THE KILLING OF PLANT TISSUE BY LOW TEMPERATURE

BY

WILLIAM HENRY CHANDLER, B. S. AGR., M. S. AGR.

SUBMITTED IN PARTIAL FULFILLMENT OF THE
REQUIREMENTS FOR THE DEGREE OF
DOCTOR OF PHILOSOPHY
IN THE

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Reprinted from Research Bulletin No. 8, Missouri Agricultural Experiment Station

BIOGRAPHY.

WILLIAM HENRY CHANDLER

I was born July 31, 1878, on a farm in Bates county, Missouri. My common school education was secured in the Public Schools of this county, and, later, I attended the Butler Academy at Butler, Missouri. For several years I served as a teacher in the public schools of Bates county.

In September, 1901, I entered the College of Agriculture of the University of Missouri. The degree of Bachelor of Science in Agriculture was given to me in 1905. For the school year of 1905-6 I served as Fellow in Horticulture at the University of Missouri and in June, 1906, took the degree of Master of Science in Agriculture. The subject of my thesis was: "Winter Killing of Peach Buds as Influenced by Previous Treatment of the Trees."

In 1906, I became Assistant in Horticulture, University of Missouri, and in 1909, Instructor in Horticulture. My rank was raised to Assistant Professor of Horticulture in 1911. I was elected Professor of Research in Pomology, Cornell University, in 1913, which position I still hold.

I have published, or have in press, the following papers of the Missouri Agricultural Experiment Station:

Bulletin 74 The Winter Killing of Peach Buds as Influenced by Previous Treatment of the Trees.
Bulletin 97 Co-operation Among Fruit Growers.
Bulletin 102 Combating Orchard and Garden Enemies.
Bulletin 113 Commercial Fertilizers for Strawberries.
Research Bulletin 8 The Killing of Plant Tissue by Low Temperature.
Research Bulletin 14 Sap Studies with Horticultural Plants.

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THE KILLING OF PLANT TISSUE BY LOW TEMPERATURE

W. H. Chandler

Summary

1. The term sap density, as often used in this publication, refers, not to specific gravity, but to molar concentration. These sap densities have been determined by the freezing point method, making use of the fact that the molecular weight in grams of any non-electrolyte lowers the freezing point 1.86° C. The sap density is generally given in terms of depression, meaning the number of degrees Centigrade that the freezing point is lower than the freezing point of water.

2. By the eutectic point is meant the temperature at which the substance in solution crystallizes out. At that temperature there would be at the same time ice, crystals of the solute, and unfrozen solutions.

3. There are several forms of injury from cold, some of them purely mechanical, such as tearing of tissue due to tension developed at low temperature, or evaporation from the surface when the conducting tissue is frozen so as to prevent the movement of water to that tissue, and killing as a result of long continued exposure to low temperature. The term *freezing to death,* however, is applied here only to a very specific set of phenomena. With all plant tissues, when a certain temperature is reached very shortly after thawing, it will be found that the tissue has taken on a brown, water-soaked appearance, and evaporation from that tissue is much more rapid than from living tissue. These are characteristics of plant tissue frozen to death.

4. Results of many investigations have shown that during freezing (which may or may not result in freezing to death), ice forms in the tissue, generally not in the cells but in the intercellular spaces, the water moving out of the cells to form crystals in these spaces. The most commonly accepted theory is that killing from cold results from the withdrawal of water from the protoplasm. The amount of water loss necessary to result in death varies with the different plants and different tissues. (Pages 9-17.)

5. In the experiments described in this bulletin, the killing temperature of plant tissue that kills at relatively high temperature has been reduced whenever the sap density of the tissue has been increased. (Pages 17-49.)

6. In addition to ripe apples and pears, and the leaves of *Agave Americana* observed by Müller-Thurgau and Molisch, leaves of lettuce kill at a slightly lower temperature if they are thawed slowly than if thawed rapidly. In case of all other tissues tested by this station or by others, including unripe apples and pears, there is no indication that the rate of thawing has anything to do with the amount of killing at a given temperature. (Pages 49-56.)

7. Rapid wilting of tissue has not generally increased the resistance of plants to low temperature over that of unwilted tissue with a dry surface. However, tissue with a wet surface killed worse at a given temperature than did tissue with no moisture on the surface. (Pages 56-60.)

8. Slow wilting or partial withholding of water through a long period increased the resistance of tissue to low temperature. (Pages 60-61.)

9. In case of hardy winter buds and wood, a rapid decline in temperature greatly increased the severity of injury from a given low temperature. (Pages 61-67.)

10. There seems to be no constant relation between the rate of growth of plant tissue and resistance to low temperature. Young leaves of fruit trees kill at a higher temperature than do old, mature leaves, while the young leaves of lettuce withstand a lower temperature than do the older leaves. (Pages 80-85.)

11. Previous exposure to low temperature above that at which the tissue kills seems to increase the resistance of tissue to low temperature. (Pages 85-86.)

12. The most important feature affecting the hardiness of plant tissue is maturity, that is, the condition of resistance that the plants reach during the winter dormant period. Maturity in the case of cambium may be intimately associated with the process of drying out. However, this can not be true at least of cortex of winter twigs. There is little difference between the moisture content of unfrozen cortex in seasons when it is very tender, and seasons when it is hardy. The wood at the base of the trunk and at the crotches of all rapidly growing branches seems to reach a condition of maturity in early winter more slowly than does most other tissue. (Page 79.)

13. Of the tissue above ground during periods when the most complete maturity is reached, the most tender parts are the pith cells and the fruit buds. During periods of rapid growth there is little difference in hardiness of the different tissues. The tissue which is most tender at all seasons of the year is the root. There

is much less difference, however, in the killing temperature of roots in summer and winter than between the killing temperature of twigs or other wood in summer and winter. (Pages 86-103.)

14. Roots of the French crab used as stock seem to be more tender than roots which come from scions of an average variety of apple. (Pages 103-105.)

15. Marianna plum roots are certainly more hardy than Myrobolan roots, and Mahaleb cherry roots seem slightly more hardy than Mazzard roots. (Pages 105-115.)

16. That part of the root system nearest the surface and the largest, oldest roots are more resistant to cold than are small roots further from the surface. (Pages 89-115.)

17. Pollen of the apple will withstand much lower temperatures than will any other tissue of the flower when in full bloom. (Page 115.)

18. Scales of peach buds do not serve to protect them from low temperature. Buds frozen in the laboratory with the scales removed were slightly more resistant to low temperature than were buds with the scales not removed. (Pages 116-118.)

19. The killing of wood of peach trees from freezing is one of the most important determining factors in peach growing. Little can be done to influence the amount of killing except to have the trees start into winter in proper condition of maturity. The weakest growing trees, however, do not generally reach this condition of maturity in the most satisfactory manner. Trees one or two years in the orchard, or old weak trees, are most liable to succumb to effects of low temperature. Pruning the trees severely following a winter when the wood has been killed, altho apparently in the best condition of maturity, seems to reduce the amount of killing. However, such pruning following winters when the wood has been killed on account of its not having reached the proper condition of maturity in the fall, generally due to the presence of wet weather following a drought the season before, is liable to result in greater loss than if no pruning were done. (Pages 118-122.)

20. The hardiness of peach buds when in fully dormant condition seems to be greatly increased by continuous low temperature preceding the date at which the temperature goes low enough to kill. This capacity to withstand low temperatures seems likely to be due to the slow fall in temperature under such conditions rather than to hardiness developed as the result of exposure to low temperature. (Pages 122-131.)

21. In the peach growing district of South Missouri and Arkansas, and probably other similar climates, the most important factor influencing the loss of peaches from low temperatures in winter is keeping the buds from starting into growth during warm periods in winter. In that section the best means of accomplishing this end is prolonging the growth of the trees in autumn, either by heavy pruning or by fertilizing with nitrogen the spring before. Some varieties of peaches have a much longer rest period than other varieties and therefore are started into growth more slowly by warm periods in winter. (Pages 131-145.)

22. The killing temperature of peach blossoms when the tree is just coming into full bloom, under Missouri conditions, seems to vary from about 22° F. to 25 or 26° F. After the blossoms are old enough that they are probably pollinated, and from that time on until the peaches are as large as one-half inch in diameter, at least, they continue to become more tender until they will withstand but very few degrees below the freezing point, the seeds of young peaches killing at a higher temperature than other peach tissue. (Pages 145-148.)

23. So far the investigations at this station indicate that early varieties of peaches are not started into growth more readily by warm periods in winter than are later varieties. Some of the very early varieties of the Chinese Cling group are the most slowly started into growth in early winter and bloom as late as any of the varieties. However, after blooming time these early peaches grow much more rapidly and are much more liable to be killed by a freeze after the fruit is set. (Pages 148-150.)

24. Killing of wood of the apple is of considerable importance in some apple growing sections. Among the most common injuries are root killing, crown rot, crotch injury, sun scald, trunk killing and killing back of top and branches. (Pages 155-159.)

25. Killing of apple buds from low temperatures is not common but has been observed. (Pages 159-160.)

26. The blossoms and young fruit of the apple will not generally withstand as low temperature as will the blossoms or young fruit of equal age of the peach. (Pages 160-164.)

27. While the killing of cherry and plum buds is less common than the killing of buds of the peach, such killing is often to be observed in some sections. The young fruit of the Wild Goose plum is among the most resistant to late frosts in spring. (Pages 164-165.)

STUDIES ON THE KILLING OF TISSUES OF HORTICULTURAL PLANTS BY LOW TEMPERATURE

The work to be reported in this paper was begun during the season of 1904-05. At that time the studies concerned only the effect of certain cultural methods on the hardiness of the fruit buds of the peach under climatic conditions that prevail in the southern half of Missouri. Later they were extended to include the possible effect that a large amount of potassium or other mineral elements in the soil might have on the ability of the peach fruit buds to withstand cold.

In taking up this problem it is necessary to distinguish between some of the various phases of injury from cold. Various writers have mentioned observations on frost cracks, that is, a formation of cracks in the wood of the tree during freezing weather. Caspary[1] showed that the formation of these cracks is due to a greater contraction of the tissue of the tree tangentially than radially. Later, Müller-Thurgau[2] made a very careful study of these cracks and confirmed Caspary's opinion, but showed that this great contraction tangentially is due rather largely to the shrinking of the cells of the medullary rays. These medullary rays extend in lines from the center out, and are made up of rather thin walled cells separated nowhere by very rigid tissue. These rays separate wider strips of rigid tissue extending in a wedge shape from the surface to the center with no lines of more pliable tissue crossing them. Then where the cells of the medullary rays contract on the passage of water into the intercellular spaces to form ice crystals, shrinking toward the center is limited to the rate of shrinking of the strong wedges of rigid tissue, while radially there is the shrinking of the rigid tissue and the more rapid shrinking of the medullary ray tissue.

There seems to be another type of injury[3] to the wood of trees, especially the small twigs, due apparently to the fact that during a long cold period much moisture will be lost from these twigs that can not be replaced because of the frozen condition of the conducting tissue. Thus death will result from the great loss of water from the twigs by evaporation. Killing of this kind seems to be worse in regions with prevailing strong winds and continuous low winter temperature. Thus Allen[4] finds a rather direct correlation between the

[1]Bot. Zeit. Vol. 13, pp. 449-62, 473-82, 489-500 (Bibl. No. 17); Bot. Zeit. Vol. 15, pp 329-35, 343-50, 361-71 (Bibl. No. 19).

[2]Landw. Jahrb. Vol. 15, p. 453, 1886 (Bibl. No. 78).

[3]A. Nelson, Wyo. Agr. Exp. Sta. Bul. 15, 1893. (Bibl. No. 81).

[4]Master's Thesis, Iowa Agr. Exp. Sta. (Bibl. No. 2).

hardiness of the different varieties of apples and the rate at which water will be evaporated from their twigs.

Another form of injury, at least an injury that has been attributed to the effect of low temperature, results in the formation of dead areas on the bark of the tree trunk, especially near the top of the ground or in the crotches formed by the branches. Such injury has been studied by Goeppert[1], Sorauer[2], Grossenbacher[3] and others. Grossenbacher finds this injury greater on the side of the tree next to the prevailing wind, indicating that the great evaporation from the bark during a long period when it is frozen, and especially the tearing due to the bending of the tree when the bark is under high tension, may have something to do with this form of injury. This may not be a different form of injury from direct freezing to death which will be discussed later.

Sachs observed that the foliage of certain plants wilted following exposure to a temperature above the freezing point. He and also Müller-Thurgau[4] conclude that this wilting was not due directly to the effect of cold, but indirectly to the inability of the roots to take up moisture at so low a temperature to replace the evaporation from the leaves. According to Molisch[5], plants continuously exposed to a temperature too low for normal metabolism, but above the freezing point, will eventually die. Under these conditions, death ensues more slowly than where plants are killed by a sudden freeze. The plants gradually turn yellow and die, or dark colored dead spots are formed on the foliage.

Müller-Thurgau[6] limits the term freezing to death ("erfrieren") to the most common phenomena to which we have reference in speaking of killing from cold. It is death of the tissue following, directly, the lowering of the temperature below the freezing point, with the accompanying formation of ice crystals. When plant tissue is thus frozen to death in the case of growing plants, the foliage in practically all cases has a wilted or limp appearance. Pronounced color changes take place. Thus in most cases the green color due to the chlorophyll is lost, and the tissue takes on a brownish watery color. Plant cells containing coloring matter give up this coloring matter to the adjoining cells of the liquid in the intercellular spaces. Other

[1]Ueber die Wärmeentwickelung in dem Pflanzen, etc. Book, 1830. (Bibl. No. 44).
[2]Landw. Jahrb. Vol. 35, pp. 465-525. 1906. (Bibl. No. 105).
[3]N. Y. Geneva, Agr. Exp. Sta. Tech. Bul. 23, (Bibl. No. 50); N. Y. Geneva, Agr. Exp. Sta. Tech. Bul. 12, (Bibl. No. 51).
[4]Landw. Jahrb. Vol. 15, p. 453, 1886. (Bibl. No. 78).
[5]Untersuchung über das Erfrieren, etc. 1897, Book. (Bibl. No. 75).
[6]Landw. Jahrb. Vol. 15, p. 453, 1886. (Bibl. No. 78).

color changes often take place, due to chemical changes when the coloring matter comes in contact with other substances from other cells. Death[1] can often be detected by these color changes. In the case of certain buds, and especially the stem and root tissue of hardy trees, the changes indicating this sort of death from cold can not be detected so soon after thawing, but are very characteristic, the tissue showing the watery, brownish appearance in a few hours after thawing. In all cases water is very rapidly lost from tissue killed in this way. Thus Goeppert[2] has shown that 24.25 grams of frozen canna leaves, which on thawing proved to be dead, lost when kept for six days in the open air near a warm stove, 21.25 grams, while the same weight of live canna leaves lost in the same length of time only 11.27 grams. When the killing temperature is barely reached, not all of the tissue is likely to be killed, but often there will be spots of dead tissue with live tissue adjoining. It has been observed by Sorauer and others, that the number of dead cells does not increase beyond those that are easily observed to be dead a short time after thawing. However, it requires longer for death to be plainly observed in the case of some tissues than others. As mentioned above, the tissue of the sap wood and cortex does not show plainly whether or not it is dead as soon as does the tissue of leaves and buds. Sorauer[3] found that epidermal tissue is slower in showing death after thawing than other tissues.

REVIEW OF THE LITERATURE ON FREEZING TO DEATH

In this paper the term freezing to death will be used as it was used by Müller-Thurgau, only when referring to the phenomena just described. While some early observers were of the opinion that plants have the ability to generate heat within their tissue and thus avoid severe freezing, the early Greek philosophers, observing the presence of ice within the plant tissue and not knowing of the cellular structure, were of the opinion that the injury was due to rending and mashing organs by the ice formation. Du Hamel and Buffon[4] were among the first to present a theory of the cause of death from cold based on a partial knowledge of cellular structure. They believed killing to be a rupturing of the cell walls due to the expansion accompanying ice formation.

[1]Molisch, Untersuchung über das, etc. 1897. Book. (Bibl. No. 75); Muller-Thurgau, Landw. Jahrb. Vol. 15, p. 453, 1886. (Bibl. No. 78).
[2]Ueber die Wärmeentwickelung, etc. Book, 1830. (Bibl. No. 44).
[3]Landw. Jahrb., Vol. 35, pp. 469-525, 1906. (Bibl. No. 105).
[4]Mem. d. l'Acad. Roy. Sci., Paris, 1737, pp. 273-298. (Bibl. No. 30).

Goeppert[1] was among the first to make a careful study of killing from cold. He observed the formation of ice within the cells, and also in the intercellular spaces. Sachs[2] found that it was almost always in the latter.

Müller-Thurgau[3] in his very excellent studies found that when the ice crystals were found within the cells, it was due to very rapid freezing such as Goeppert used, and when the temperature was lowered very slowly, ice crystals were seldom found within the cell. Müller-Thurgau proved that ice formation within the tissue is necessary to freezing to death. It is well known that a liquid may often be supercooled several degrees below the freezing point before ice formation begins. He observed that this often occurs in cooling plant tissue in the laboratory, and when pieces of tissue (potato) were supercooled, if they could be warmed without ice formation they were not injured, while if ice formed they would kill at a higher temperature than that to which they were supercooled. Voigtlander measuring his temperatures with more delicate apparatus, has proved this perhaps more conclusively. When he supercooled tissue to four or five degrees centigrade below the point at which it would kill when ice formed, if the temperature could be raised to above the freezing point without ice formation, killing never occurred. It was held by many scientists, at the time of Müller-Thurgau's first work, as well as by a large majority of practical observers, that death was due not directly to low temperature, but to rapid thawing. Goeppert was of the opinion, however, from his studies, that the killing was a direct result of freezing and that death actually occurred before the thawing began. Sachs, from some experiments with plants immersed in cold water to thaw, after freezing, held that the amount of killing of the plants at any given temperature was determined by the rate of thawing. Müller-Thurgau showed that the method used by Sachs of thawing plants in cold water was not a method of slow thawing, but rather a very rapid thawing since a layer of ice crystals would form on the outside of the tissue, giving off heat that would thaw the tissue very rapidly. In fact the tissue thawed in cold water much more rapidly than in the air at room temperature.

Müller-Thurgau using a large number of plants, thawing them from the same temperature, some rapidly and some more slowly,

[1]Ueber die Wärmeentwickelung, etc. Book. 1830. (Bibl. No. 44).

[2]Ber. u. d. Ver. d. Kon. Sachs. Gesell. d. Wiss. zu Leipzig, 1860, Vol. 12, pp. 1-50. (Bibl. No. 94).

[3]Landw. Jahrb. Vol. 15, p. 453, 1886. (Bibl. No. 78).

was never able to detect any difference in the amount of killing when thawed rapidly or slowly, except in the case of the fruit of the apple and pear. Molisch[1], following the work of Müller-Thurgau, tried also slow and rapid thawing from the same temperature with a very large number of plants, and found that in nearly all cases the rate of thawing had nothing to do with the killing. In the case of the fruit of the apple and pear, and the leaves of Agave Americana, the slow thawing gave less injury, but even with these, a slightly lower temperature than that at which they kill with rapid thawing, would kill them, regardless of the rate of thawing. Müller-Thurgau observed carefully the freezing of tissue under the microscope and found that ice was very seldom formed within the cell, but usually ice crystals formed outside the cell in the intercellular spaces and continued to increase in length as the temperature went lower, the water passing from the cell into the intercellular spaces increasing the length of the crystals.

By placing plant tissue frozen to various temperatures in 100 cc. of water carefully insulated, and noting the temperatures to which the water was lowered, excluding the losses of heat for warming up the plant tissue, correcting for the heat of the beaker, etc., making use of the fact that eighty gram calories are required to melt one gram of ice, Müller-Thurgau[2] was able to determine, apparently with some accuracy, the percentage of the plant water that is frozen into ice at various temperatures. Only plant tissue with a determined moisture content was used. With the apple he gives the following percentages of water frozen out at given temperatures: at -4.5°, 63.8 per cent of the water was frozen; at -13°, 74.4 per cent of the water was frozen; at -15.2°, 79.2 per cent of the water was frozen He also attempted to measure the percentage of the water frozen out of woody tissue by means of frost cracks. His method was to freeze a section of a young tree trunk until a frost crack of a certain width was formed. On thawing of the tissue this crack would close. His next step was to dry the section of tree trunk until a frost crack of the same width was formed. He assumed that the percentage of water loss necessary to form this crack is equal to the percentage taken from the cell during freezing sufficient to form an ice crack of the same width.

Molisch studied with great care, under the microscope, the freezing of various plant tissues, observing the same phenomena de-

[1]Untersuchung über das, etc. 1897, book. (Bibl. No. 7[illegible]).
[2]Landw. Jahrb. Vol. 9, p. 453, 1886. (Bibl. No. 78).

scribed by Müller-Thurgau with reference to the freezing of the cell water in the intercellular spaces, rather than within the cells. Both Müller-Thurgau and Molisch hold the view that freezing to death results from the rapid withdrawal of water from the cells to form these ice crystals in the intercellular spaces.

Matruchot and Molliard[1] observed that water is extruded from the nuclei of plants that have been frozen, dried or subjected to the action of solutions of high osmotic concentration.

Gorke has recently offered an interesting theory as to the cause of death by freezing. He found that when the plant sap is frozen, certain proteids may be precipitated out and apparently those plants that are most easily killed by freezing have their proteids precipitated out at the highest temperature. Thus begonia, which is very easily killed, had its proteids precipitated at -3° while sap from pine needles required a temperature of -40° to precipitate any proteids. Gorke[2] assumes then that killing from cold may be due to the precipitation of the proteids, and accounts for this precipitation by the greater concentration of the salts in the sap as water is removed to form ice crystals. It is well known that certain proteids can be precipitated out by increasing the concentration of salts, especially zinc sulphate and ammonium sulphate. Gorke made up solutions of albumen with zinc sulphate and found that after freezing to -20° there was a large precipitation of proteids.

Lidforss[3] working with the wintergreen plants of South Sweden, has found that with most of them at least during cold weather, the starch is almost entirely changed to sugar, though on the return of warm weather starch may be again deposited in the cell. He assumes that this sugar is formed during cold weather as a means of protecting the plant against freezing by lowering the freezing point of its sap. He was able also to increase the resistance to low temperature of the leaves of wintergreen plants and the roots of *Zea Mays* by keeping them for a time immersed in 5 to 10 per cent sugar solutions.

Schaffnit[4], following the work of Gorke, found that the proteids of rye grown in the open at low temperatures are not readily precipitated by freezing, while the same temperature will readily precipitate proteids from sap of rye grown in the greenhouse at much

[1]Compt. Rend. Acad. Sci. Paris, Vol. 132 (1901) pp. 495-8. (Bibl. No. 71a)

[2]Land. Versuchs. Vol. 65, p. 149, 1906. (Bibl. No. 47).

[3]Lunds Universitets Arssk., Vol. 2, No. 13, 1907 (Bibl. No. 62); Bot. Centlb., Vol. 68 No. 2, p. 33. (Bibl. No. 63).

[4]Mitt. Kaiser Wilhelm Inst. Landw. Bromberg, Vol. 3, No. 2, pp. 93-115, (Bibl. No. 98); Zeits. f. Allg. Phys., Vol. 12, pp. 323-36. (Bibl. No. 99)

higher temperatures. He also found that he could prevent the precipitation of proteids from this sap of greenhouse rye by adding to it small quantities of sugar. He concludes then that the formation of sugar in wintergreen plants described by Lidforss may be the means of protecting the plants against precipitation of proteids. However, Schaffnit concludes that precipitation of proteids is the only way by which loss of water during freezing kills plant tissue.

Maximow[1] has recently published three very interesting papers covering work in freezing sections of plants, mainly red cabbage and *Tradescantia discolor*. Thin sections of tissue from the upper side of the leaves were frozen in solutions of various strengths of both organic and inorganic substances after they had stood for varying lengths of time in the solutions. He found remarkable protection to be exerted by both organic and inorganic substances whenever their eutectic point (the temperature at which they crystallize out, giving mixtures of solute crystals with the ice crystals) does not lie too near the freezing point and whenever the substance is not excessively toxic. He used strengths varying from $\frac{N}{16}$ to 2N of glucose and glycerine, and $\frac{N}{8}$ to 2N of methyl and ethyl alcohol, and mannite. Of inorganic substances he used solutions with strengths of 0.1N to 2N of sodium chloride, potassium chloride, calcium chloride, sodium nitrate, potassium nitrate, calcium nitrate, sodium acetate, potassium acetate, calcium acetate, sodium lactate, potassium lactate, sodium oxalate, and potassium oxalate, also magnesium nitrate, magnesium chloride, ammonium nitrate, ammonium chloride, sodium sulphate, and potassium sulphate.

According to Maximow, mannite, sodium sulphate, potassium sulphate. potassium nitrate, and sodium oxalate show little protection because of their high eutectic point; and magnesium chloride, magnesium nitrate, and ammonium chloride because of their toxicity, while calcium chloride and calcium nitrate show reduced protection because of their toxicity. All other solutions, however, showed great protection that was very uniform for the same osmotic concentration. Sometimes a temperature as low as -32° did not kill all of the cells of the red cabbage. Probably the most interesting result of Maximow's work was the observation that when the sections were immersed in these solutions and immediately frozen, as much protection was exerted as when they had been permitted to remain in the solutions for twenty-four hours or longer. The tender Tradescantia cells immersed in expressed sap of the red cabbage and im-

[1]Ber. der Deutsch. Bot. Gesell., Vol. 30, pp. 52-65, 293-305, 504-16, (Bibl. No. 73)

mediately frozen, would actually withstand more cold than the hardier red cabbage when frozen in winter. Maximow concludes that the part of the cell which is injured when exposed to low temperature is the plasma membrane, and that as long as a film of water was kept in contact with this membrane, death was not likely to occur His theory then would not be greatly different from that of Müller-Thurgau and Molisch, that withdrawal of water kills, except that in Maximow's opinion killing following the withdrawal of water seems to be limited to the plasma membrane.

If Maximow's work is verified by further experimenting, using other plants, it is certainly a very interesting contribution toward determining just what freezing to death of plant tissue is.

Mez[1] studied the effect of supercooling upon plant tissue. He finds that where ice formation begins at once on reaching the freezing point, the killing is not so great as where there is supercooling when large masses of ice are formed rapidly after crystallization begins. By use of the thermo-couple he studied the fall of temperature in the plant, using stems of *Impatiens* to determine the eutectic points of the sap solutes. At each of these points there will be a halting in the temperature fall due to the heat given off on crystallization. From this work he concludes that when a temperature of -6° is reached, all solutes will crystallize out. He thinks this should disprove the theory of Müller-Thurgau and Molisch, since there should be complete loss of water at this temperature and the plant should never survive a lower temperature if loss of water from the cell is the cause of death. He holds that the heat liberated by the crystallizing of the solutes and the formation of ice, will after the cells are insulated by the ice mass, aid in keeping the temperature of the cell above that of the surroundings. He holds, therefore, that each plant has its specific minimum point at which death occurs due to the direct effect of the cold, and that if supercooling takes place, large amounts of heat are lost before the cells are insulated by the ice mass and therefore this specific minimum will be more quickly reached. The work of Müller-Thurgau[2] and of Voigtlander[3], (a pupil of Mez) where plants supercooled to below the killing temperature remained alive if ice did not form, certainly refutes the theory of Mez. If further evidence were needed, the protective action of organic and inorganic substances shown in Maximow's work certainly proves the fallacy of Mez's conclusion. Even his conclusion that the sap solute

[1]Flora, Vol. 94, p. 89, 1905. (Bibl. No 74).
[2]Landw. Jahrb. Vol. 15, p. 453, 1886. (Bibl. No. 78).
[3]Beitr. z. Biol. der Pfl. Cohn. Vol. 9, 1909, pp. 359-414. (Bibl. No. 110).

FIGURE I.—FREEZING APPARATUS FOR PLANTS THAT KILLED AT A TEMPERATURE NOT LOWER THAN –12° TO –15° C.

1. Space in which salt and ice mixture was placed;
2. Chamber in which plants were frozen;
3. Lid which covered freezing chamber;
4. Wire leading to small electric fan beneath hardware cloth bottom on which plants were frozen. (See page 156.)

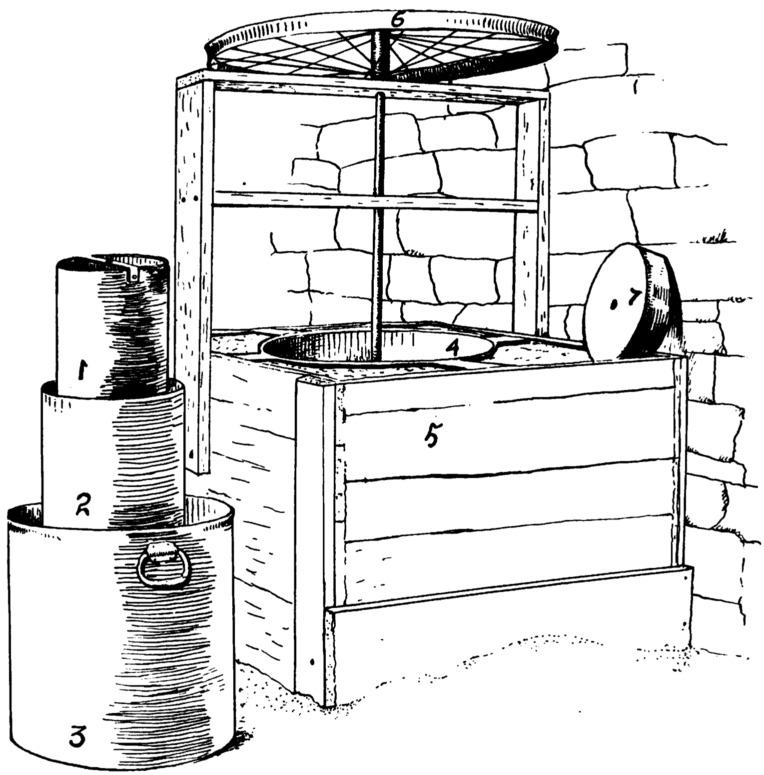

FIGURE II.—APPARATUS FOR FREEZING TISSUE THAT REQUIRED LOWER THAN −12° TO −15° C. TO KILL.

1. Galvanized iron cylinder to the bottom of which the twigs containing buds were fastened; 2 and 3. Galvanized iron cylinders placed one within the other with space between their walls for freezing mixture; 4. Cylinder to receive 3, allowing space for freezing mixture around 3; 5. Insulating box filled with sawdust; 6. Wheel operated by electric motor and belt in order to keep (1) turning continuously while freezing; 7. Lid for (2). (See page 157.)

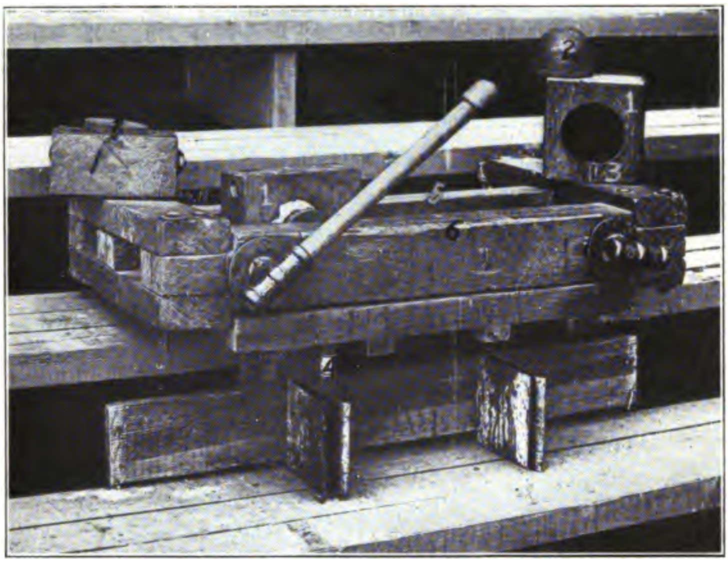

FIGURE III.—APPARATUS FOR EXPRESSING PLANT JUICE.

The two blocks between which the plant tissues were pressed are shown at (1) and (2). The juice escaped through a hole (3) in block (1). The plant tissue was placed between the blocks (1) and (2), which in turn were placed between the pieces of movable 4″x4″ pieces which are drawn together by bench-screws. (See page 158.)

must all be crystallized out at -6° C. can not be true since sugars would remain in solution at lower temperatures than that. Further, when we have evaporated the cortex sap of peach twigs in winter condition to one-sixth or one-eighth of its volume without permitting the temperature to go above 50° C. ice would not form when the temperature was lowered to -22° C. though many of the buds would be killed at that temperature. Mez seems also to ignore the force of imbibition which would tend to hold the water in the protoplasm even after the sap solute may be crystallized out. The fact, however, that when great supercooling takes place, plants are more liable to be killed, is of interest and is, of course, associated with the fact which will be discussed later that rapid cooling is more injurious to plant tissue than is slow cooling.

EFFECT OF SAP DENSITY ON KILLING TEMPERATURE.

If the theory of Müller-Thurgau and Molisch be true (even as it is modified by Maximow) it would seem that some plants might be hardy because the plasma membrane has the property of withstanding great loss of water. Some might be relatively hardy because of a property by which sufficient water to protect the plasma membrane at low temperatures is prevented from freezing, and some might be relatively hardy on account of the presence of both conditions. It is generally considered that after the effect of the sap solute in holding water unfrozen is exhausted, there is still left the force of imbibition. The relative importance of these two forces, however, is not determined. Disregarding the force of imbibition (which, however, may be the more important), it would appear to be true that if the sap density (by sap density is meant not specific gravity but molar concentration of the sap; that is, the number of gram molecules of the sap solute in one thousand grams of water) were doubled, then at any given temperature below the freezing point, but above the eutectic point of the solute, twice as much water would be held unfrozen to protect the protoplasm.

With this idea in mind, experiments were started in September, 1908, to determine whether or not an increase in the sap density would lower the killing temperature.

Seedlings of corn, cowpeas, garden peas, tomatoes, squash, cabbage and lettuce were grown in sand and watered with varying strengths of potassium chloride and ammonium chloride at first—later magnesium chloride, sodium chloride and sodium nitrate were also used—while check plants were grown under similar conditions

except that they were watered only with distilled water. The plants were permitted to grow only as long as they would make good growth in the sand, probably about the time the food supply of the seed was becoming exhausted. Some of the plants of each set were then frozen while others had the sap expressed for osmotic strength (freezing point) determination by the use of a Beckmann apparatus. As a measure of the osmotic strength the term depression will be used in the tables, meaning of course the number of degrees centigrade below zero at which, with no supercooling, ice formation begins in the sap.

Method of Freezing. At first an effort was made to grow the plants in the greenhouse and expose them to outside temperatures to determine the killing temperature. However, this was soon found to be unsatisfactory and the plants were frozen in a chamber surrounded by a freezing mixture made of salt and ice. It is evident that the temperature throughout such a chamber would not be uniform so long as it were falling and great care was necessary to secure as uniform a temperature as possible. The apparatus shown in Fig. 1 was used. In the lower part was an electric fan; the upper part was the chamber in which the plants were frozen. An effort was made to keep the temperature uniform within this chamber by the operation of the electric fan just beneath the hardware cloth shelf on which the plants were frozen. Careful tests showed that the temperature throughout this chamber was always uniform on the same level though sometimes it would vary slightly in different levels. Fearing, however, that this would not always be true, the plants on freezing were always placed, not only on the same level, but at the same distance from the galvanized iron wall of the chamber. In this way it was practically impossible that plants in the freezer would not all be exposed to the same temperature, and consistent results were secured.

In addition to being sure that the plants were at a uniform temperature, it was necessary to control very carefully the rate of fall of the temperature, since rapid falling of temperature very greatly increases the killing. For this reason it was practically impossible to secure results that would be sufficiently accurate so that one freezing could be compared with another, except where differences were wide; that is, the plants to be compared must be frozen at the same time. However, when the differences are large it is possible to make a fairly accurate estimate of the relative hardiness of the plants frozen at different times, if great care is taken to duplicate as nearly as possible, the rates of temperature fall. It was found possible to

lower the temperature of all the plants together to a point that would probably kill the most tender, and after removing these to lower it further. The rate of fall would thus be the same for all down to the temperature at which the most tender were removed.

The thermometer used in the earlier years of freezing was a pentane thermometer graduated to one-half degrees. The zero point was far enough above the bulb so that when the thermometer was inserted through a cork at the top of the jacket of the freezing chamber, the bulb would be on the same level with the plants. Later, special mercury thermometers graduated to low temperature were used. These were standardized by the makers. However, new thermometers were checked by those used with previous work, and also, checked from time to time, with standard thermometers of the Columbia Branch of the United States Weather Bureau. No effort was made to read the thermometers to closer than one-half degrees. Plants on being removed from the freezer were always examined to see if the tissue were frozen stiff. In freezing buds and woody tissue that killed at a temperature lower than -15°, the apparatus shown in figure 2 was used. The twigs or pieces of tissue and the thermometer were fastened to the inner cylinder which was filled with cotton. This was set in a cylinder enough larger to leave a surrounding space of about three-fourths of an inch. The second cylinder was about six inches taller than the inner one, and was set with a one and one-half inch space between them. There was about two inches of space between the walls of this third cylinder and those of the one in which this was placed. The fourth cylinder was well insulated by being packed in dry saw dust. Ice and salt were first packed loosely and then firmly in the space between the fourth and third cylinder. In this way the temperature of the twigs could be lowered generally to -17° C. When it was necessary to secure a lower temperature, the space between the third and second cylinders was packed loosely and later firmly with salt and ice. In this way the temperature of the air surrounding the inner cylinder could be gradually lowered at the rate of two to three degrees an hour after the freezing point was reached. By packing salt and ice to the top of the second cylinder the temperature from top to bottom of the inner cylinder would vary but little. However, the freezing tissue to be compared and the thermometer bulb were always kept the same distance from the bottom of the cylinder. Since these cylinders were of galvanized iron and would conduct heat rapidly, it would seem probable that the temperature around the central cylinder would not vary. However, fearing that there might be some such variation in temperature, the

central cylinder with the twigs or woody tissue and the thermometer on its surface was kept slowly revolving by means of a small electric motor. During the freezing, this was stopped only for thermometer readings which were taken generally every fifteen minutes.

Method of Determining Freezing Point of Sap. The density of sap was determined by means of a Beckmann Freezing Point Apparatus. The tissue was ground in an ordinary food grinder, using the knife that grinds the finest, and the sap was expressed with the apparatus shown in Figure 3. The large block with the hole in the center is of sugar maple which will not split readily. The smaller block is of the same material and is made to fit in the depression in the large block leaving about one-eighth of an inch surrounding space. The ground tissue was wrapped in a clean piece of eight or ten ounce duck and put in the depression in the large block, the small block put against it and the two pressed together between pieces of 4x4 lumber drawn together by a pair of bench screws as shown in the figure. The sap could be expressed very quickly. With succulent plants loss by evaporation in all cases was negligible. In the case of leaves of peaches it required a considerable length of time for the sap to exude.

In all cases before plants with different treatments were frozen or before they were ground for expressing sap, they were, after being pulled, kept with the roots in a glass of water until they became apparently turgid, since wilting sometimes seems to reduce slightly the killing temperature, and would appreciably affect the sap density determinations.

EXPERIMENTS WITH SEEDLINGS OF ZEA MAYS

A large number of corn seedlings were grown and frozen. The following table gives the date of freezing, the solution with which the material was watered, the temperature to which the plants were subjected, the percentage killed and percentage partly killed, and the freezing point of the sap. The freezing point is given as depression, meaning the number of degrees below zero, centigrade, at which ice begins to form in the sap, assuming no supercooling.

TABLE 1. SHOWING EFFECT OF WATERING WITH MINERAL SOLUTIONS ON SAP DENSITY AND HARDINESS IN ZEA MAYS PLANTS.

Watered With	Date	Temperature	Number Plants	Percentage Killed	Percentage Killed and Partly Killed	Depression
Potassium Chloride (.0804 N)........	Dec. 12,'08	-3	6	33.3	83.3	1.10
Potassium Chloride (.0402 N).........	Dec. 12,'08	-3	6	16.6	100	1.06
Ammonium Chloride (.0804 N).........	Dec. 12,'08	-3	6	33.3	100	.94
Ammonium Chloride (.0402 N).........	Dec. 12,'08	-3	6	50	100	1.19
Potassium Chloride (.0804 N).........	Dec. 15,'08	-3	6	33.3	33.3	1.265
Potassium Chloride (.0402 N).........	Dec. 15,'08	-3	5	40	60	.94
Ammonium Chloride (.0804 N).........	Dec. 15,'08	-3	4	0	0	1.16
Ammonium Chloride (.0402 N).........	Dec. 15,'08	-3	6	100	100	.875
Potassium Chloride (.0804 N).........	Dec. 16,'08	-3.25	7	42.8	71.7	1.26
Potassium Chloride (.0402 N).........	Dec. 16,'08	-3.25	7	14.3	57.1	.94
Ammonium Chloride (.0804 N).........	Dec. 16,'08	-3.25	6	50	100	1.16
Ammonium Chloride (.0402 N).........	Dec. 16,'08	-3.25	9	33.3	88.9	.875
Potassium Chloride (.0804 N).........	Jan. 9,'09	-7	13	46.2	61.5	1.315
Potassium Chloride (.0402 N).........	Jan. 9,'09	-7	11	63.6	81.8	1.195
Ammonium Chloride (.0804 N).........	Jan. 9,'09	-7	9	77.8	100	1.005
Ammonium Chloride (.0402 N).........	Jan. 9,'09	-7	12	66.6	100	.935
Potassium Chloride (.0804 N).........	Jan. 9,'09	-6.5	11	27.3	54.5	1.315
Potassium Chloride (.0402 N).........	Jan. 9,'09	-6.5	13	61.5	84.6	1.195
Ammonium Chloride (.0804 N).........	Jan. 9,'09	-6.5	10	80	90	1.005
Ammonium Chloride (.0402 N).........	Jan. 9,'09	-6.5	14	50	85.7	.935
Potassium Chloride (.0804 N).........	Jan. 9,'09	-7.5	13	61.5	76.9	1.315
Potassium Chloride (.0402 N).........	Jan. 9,'09	-7.5	12	75	83.3	1.195
Ammonium Chloride (.0804 N).........	Jan. 9,'09	-7.5	8	87.5	100	1.005
Ammonium Chloride (.0402 N).........	Jan. 9,'09	-7.5	12	91.6	91.6	.935
Potassium Chloride (.0804 N).........	Jan. 19,'09	-3	12	16.6	50	1.315

Watered With	Date	Temperature	Number Plants	Percentage Killed	Percentage Killed and Partly Killed	Depression
Potassium Chloride (.0402 N).........	Jan. 19,'09	-3	16	18.8	43.8	1.195
Ammonium Chloride (.0804 N).........	Jan. 19,'09	-3	17	11.8	41.3	1.005
Ammonium Chloride (.0402 N).........	Jan. 19,'09	-3	11	27.3	54.5	.935
Potassium Chloride (.0804 N).........	Jan. 19,'09	-6.5	20	25	40	1.315
Potassium Chloride (.0402 N).........	Jan. 19,'09	-6.5	16	25	37.5	1.195
Ammonium Chloride (.0804 N).........	Jan. 19,'09	-6.5	11	66.6	66.6	1.005
Ammonium Chloride (.0402 N).........	Jan. 19,'09	-6.5	18	11.1	16.7	.935
Potassium Chloride (.0804 N).........	Jan. 19,'09	-6	13	7.7	15.4	1.315
Potassium Chloride (.0402 N).........	Jan. 19,'09	-6	12	0	0	1.195
Ammonium Chloride (.0804 N).........	Jan. 19,'09	-6	11	0	0	1.005
Ammonium Chloride (.0402 N).........	Jan. 19,'09	-6	12	0	0	.935
Potassium Chloride (.0804 N).........	Jan. 21,'09	-4.5	21	61.9	66.6	.93
Potassium Chloride (.0402 N).........	Jan. 21,'09	-4.5	19	68.4	68.4	.92
Ammonium Chloride (.0804 N).........	Jan. 21,'09	-4.5	15	86.7	93	.995
Ammonium Chloride (.0402 N).........	Jan. 21,'09	-4.5	19	57.9	63.2	.88
Potassium Chloride (.0804 N).........	Jan. 21,'09	-4	16	0	12.5	.93
Potassium Chloride (.0402 N).........	Jan. 21,'09	-4	17	17.6	23.5	.92
Ammonium Chloride (.0804 N).........	Jan. 21,'09	-4	17	17.6	23.5	.995
Ammonium Chloride (.0402 N).........	Jan. 21,'09	-4	16	37.5	50	.88
Potassium Chloride (.0804 N).........	Feb. 2,'09	-5	10	0	50	1.49
Potassium Chloride (.0402 N).........	Feb. 2,'09	-5	9	11.1	66.7	1.143
Ammonium Chloride (.0804 N).........	Feb. 2,'09	-5	11	0	54.5	1.17
Ammonium Chloride (.0402 N).........	Feb. 2,'09	-5	13	30.8	38.5	1.325
Potassium Chloride (.0804N), average...........				29.6	51.3	1.238
Potassium Chloride (.0402N), average...........				34.3	58.9	1.091
Ammonium Chloride (.0804N), average..........				42.6	64.1	1.037
Ammonium Chloride (.0402N), average..........				46.3	65.8	.969

It will be seen from these tables that by taking an average of a large number of these freezings, the percentage of killing is uniformly lower when the depression is increased.

Shaded Zea Mays seedlings were watered with .0804 N potassium chloride, and others with water with results as follows:

TABLE 2. SHOWING EFFECT OF WATERING WITH MINERAL SOLUTIONS ON SAP DENSITY AND HARDINESS OF SHADED ZEA MAYS PLANTS.

Watered With	Date	Temperature	Number of Plants	Percentage Killed	Percentage Killed and Partly Killed	Depression
Potassium Chloride (.0804 N)	Feb. 2,'09	–3	18	5.6	5.6	.93
Water	Feb. 2,'09	–3	17	17.6	17.6	.835
Potassium Chloride (.0804 N)	Feb. 2,'09	–5	17	41.2	58.8	.93
Water	Feb. 2,'09	–5	14	78.6	78.6	.835
Potassium Chloride (.0804 N)	Feb. 2,'09	–5	14	64.3	85.7	.93
Water	Feb. 2,'09	–5	15	80	80	.833
Potassium Chloride (.0804 N)	Feb. 12,'09	–5	8	12.5	50	1.22
Water	Feb. 12,'09	–5	7	57.1	71.4	.65
Potassium Chloride (.0804 N)	Feb. 12,'09	–4.5	8	50	75	1.22
Water	Feb. 12,'09	–4.5	9	100	100	.653
Potassium Chloride (.0804N), average				34.7	55.0	1.046
Water, average				66.7	69.5	.761

The following table gives results of freezing cowpea seedlings that had been watered with solutions containing 6.03% normal potassium chloride, sodium chloride, magnesium chloride, ammonium chloride, sodium nitrate, and distilled water.

TABLE 3. EFFECT OF WATERING WITH MINERAL SOLUTIONS ON SAP DENSITY AND HARDINESS OF COWPEAS.

Watered With	Date	Temperature	Number Leaves	Percentage Killed	Percentage Killed and Partly Killed	Depression
Potassium Chloride....	June 29,'11	-3.5	35	45.71	57.14	1.05
Sodium Chloride......	June 29,'11	-3.5	35	28.57	48.57	1.065
Magnesium Chloride..	June 29,'11	-3.5	33	69.69	100.00	.975
Ammonium Chloride...	June 29,'11	-3.5	33	3.03	15.15	1.035
Sodium Nitrate.......	June 29,'11	-3.5	33	9.09	33.33	1.05
Distilled Water........	June 29,'11	-3.5	40	77.50	77.50	.825
Potassium Chloride....	June 29,'11	-3.5	30	56.66	70.00	1.05
Sodium Chloride......	June 29,'11	-3.5	36	30.55	38.88	1.065
Magnesium Chloride...	June 29,'11	-3.5	36	66.66	77.77	.975
Ammonium Chloride...	June 29,'11	-3.5	29	58.62	75.86	1.036
Sodium Nitrate.......	June 29,'11	-3.5	24	70.83	79.16	1.05
Distilled Water........	June 29,'11	-3.5	36	91.66	97.22	.825
Potassium Chloride....	July 18,'11	-3	21	33.33	42.85	1.13
Sodium Chloride......	July 18,'11	-3	22	36.36	54.54	1.17
Magnesium Chloride...	July 18,'11	-3	30	85.33	100.00	1.00
Ammonium Chloride...	July 18,'11	-3	12	83.33	91.66	1.155
Sodium Nitrate.......	July 18,'11	-3	12	0.0	41.66	1.23
Distilled Water........	July 18,'11	-3	30	90.00	100.00	.78
Potassium Chloride....	July 19,'11	-2.75	12	100.00	100.00	1.13
Sodium Chloride......	July 19,'11	-2.75	12	66.66	66.66	1.17
Magnesium Chloride...	July 19,'11	-2.75	29	93.10	100.00	1.00
Ammonium Chloride...	July 19,'11	-2.75	12	83.33	100.00	1.155
Sodium Nitrate.......	July 19,'11	-2.75	12	0.0	58.33	1.23
Distilled Water........	July 19,'11	-2.75	30	76.66	83.33	.78
Potassium Chloride....	July 20,'11	-2.75	12	16.66	58.33	1.13
Sodium Chloride......	July 20,'11	-2.75	12	8.33	33.33	1.17
Magnesium Chloride...	July 20,'11	-2.75	12	58.33	75.00	1.00
Ammonium Chloride...	July 20,'11	-2.75	12	16.66	50.00	1.155
Sodium Nitrate.......	July 20,'11	-2.75	12	58.33	83.33	1.23
Distilled Water........	July 20,'11	-2.75	30	80.00	93.33	.78
Potassium Chloride....	July 21,'11	-2.75	12	8.33	16.66	1.13
Sodium Chloride......	July 21,'11	-2.75	12	0.00	8.33	1.17
Magnesium Chloride...	July 21,'11	-2.75	13	15.39	30.77	1.00
Ammonium Chloride...	July 21,'11	-2.75	12	8.33	16.66	1.155
Sodium Nitrate.......	July 21,'11	-2.75	12	16.66	16.66	1.23
Distilled Water........	July 21,'11	-2.75	30	86.66	93.33	.78
Potassium Chloride, average....................				43.45	57.49	1.10
Sodium Chloride, average......................				28.41	41.72	1.135
Magnesium Chloride, average....................				64.75	80.59	.991
Ammonium Chloride, average....................				33.05	58.22	1.115
Sodium Nitrate, average........................				25.82	52.08	1.17
Distilled Water, average........................				83.73	90.78	.795

It may be said, however, that the solutions all reduced the growth of the plants, as indicated by the following weights:

Average weight of plants watered with Potassium Chloride........2.27 grams
Average weight of plants watered with Sodium Chloride...........1.89 grams
Average weight of plants watered with Magnesium Chloride.......2.33 grams
Average weight of plants watered with Ammonium Chloride.......1.78 grams
Average weight of plants watered with Sodium Nitrate............1.68 grams
Average weight of plants watered with Distilled Water............2.63 grams

The percentage of killing will thus be seen to be as much in proportion to growth as in inverse proportion to depression.

Corn seedlings were also grown where water was withheld, being watered only when it was necessary to keep them from dying. The following table gives the results:

TABLE 4. SHOWING EFFECT OF WITHHOLDING WATER ON SAP DENSITY AND HARDINESS OF ZEA MAYS.

Treatment	Date	Temperature	Number Plants	Percentage Killed	Percentage Killed and Partly Killed	Depression
Well watered..........	Feb. 2,'09	-4	13	84.6	92.3	.785
Water withheld.......	Feb. 2,'09	-4	10	0.0	40.	1.07
Well watered..........	Feb. 2,'09	-5	13	61.5	74.6	.835
Water withheld.......	Feb. 2,'09	-5	5	20.0	80.0	1.07
Well watered..........	Feb. 2,'09	-5.5	12	66.7	100.0	.835
Water withheld.......	Feb. 2,'09	-5.5	6	16.7	50.0	1.07
Well watered..........	Feb. 12,'09	-4.5	10	60.0	60.0	.71
Water withheld.......	Feb. 12,'09	-4.5	9	44.5	44.5	1.085
Well watered, average..........................				68.19	81.72	.791
Water partially withheld, average................				20.27	53.60	1.074

It will be seen again that withholding water increased the sap density (depression) and lowered the killing temperature. It also reduced the rate of growth and probably the size of the cells, so we can not conclude with certainty that the greater hardiness is due only to the greater sap density.

Tomatoes were grown in the same way except that there were three lots—some well watered, others watered only when it was necessary to keep them from dying, and some others grown outside at a temperature considerably lower than that in the greenhouse. The following table gives the results:

TABLE 5. SHOWING EFFECT OF CONDITION OF GROWTH ON SAP DENSITY AND HARDINESS OF TOMATOES.

Treatment	Date	Temperature	Number of Plants	Result of Freezing	Depression
Out of doors....	Apr. 29,'11	−2	4	All dead..............	0.73
Greenhouse, wet	Apr. 29,'11	−2	4	Leaves all dead; stems slightly injured......	0.84
Greenhouse, dry	Apr. 29,'11	−2	4	Uninjured except very young leaves.........	1.16
Out of doors....	May 2,'11	−2	4	All dead (larger and stockier)............	.73
Greenhouse, wet	May 2,'11	−2	4	Leaves dead; lower stems alive..........	0.84
Greenhouse, dry	May 2,'11	−2	4	Only few leaves killed	1.16
Out of doors....	May 4,'11	−2.5	4	Foliage and upper one-third stems killed....	0.73
Greenhouse, wet	May 4,'11	−2.5	4	All killed..............	0.84
Greenhouse, dry	May 4,'11	−2.5	4	Leaves killed; stems uninjured..............	1.16
Out of doors....	May 6,'11	−2.5	4	Leaves killed; stems uninjured..............	.73
Greenhouse, wet	May 6,'11	−2.5	4	Leaves dead; upper one-third stems dead.....	0.84
Greenhouse, dry	May 6,'11	−2.5	4	Foliage and growing tips of three plants dead; one plant uninjured.............	1.16

Contrary to what might be expected, those tomato plants grown in the greenhouse but watered sparingly were more hardy than those grown outside; also the depression was greater. The results in this table again indicate that as the depression is lowered, plants are made more hardy.

Cabbage, kale and turnips were each grown in the greenhouse some watered well and others with water withheld except when it was necessary to keep the plants alive, while others were grown out of doors. The following table give results, and depressions for these plants.

TABLE 6. SHOWING INFLUENCE OF CONDITION OF GROWTH ON SAP DENSITY AND HARDINESS.

Treatment	Date	Temperature	Number of Leaves	Percentage Killed	Percentage Killed and Partly Killed	Depression
CABBAGE						
Out of doors	Nov. 2,'11	-5.5	3	0	0	....
Greenhouse, dry	Nov. 2,'11	-5.5	3	0	0	....
Greenhouse, wet	Nov. 2,'11	-5.5	3	33.4	33.4	....
Out of doors	Nov. 4,'11	-6	3	0	0	....
Greenhouse, dry	Nov. 4,'11	-6	3	0	0	....
Greenhouse, wet	Nov. 4,'11	-6	3	66.7	66.7	....
Out of doors	Nov. 17,'11	-6.5	4	0	0	....
Greenhouse, dry	Nov. 17,'11	-6.5	5	100	100	....
Greenhouse, wet	Nov. 17,'11	-6.5	5	100	100	....
Out of doors	Dec. 9,'11	-5	4	0	0	....
Greenhouse, dry	Dec. 9,'11	-5	4	100	100	....
Greenhouse, wet	Dec. 9,'11	-5	4	100	100	....
Out of doors	Dec. 9,'11	-5	4	0	0	....
Greenhouse, dry	Dec. 9,'11	-5	4	100	100	....
Greenhouse, wet	Dec. 9,'11	-5	4	100	100	....
Out of doors	Dec. 13,'11	-4	3	0	0	1.18
Greenhouse, dry	Dec. 13,'11	-4	3	0	0	.90
Greenhouse, wet	Dec. 13,'11	-4	2	100	100	.99
Out of doors, average				0	0	....
Greenhouse, dry; average				50	50	....
Greenhouse, wet; average				83.3	83.3	....
TURNIPS						
Out of doors	Nov. 2,'11	-5.5	3	0	100	....
Greenhouse, dry	Nov. 2,'11	-5.5	3	100	100	....
Greenhouse, wet	Nov. 2,'11	-5.5	3	100	100	....
Out of doors	Nov. 4,'11	-6	3	0	0	....
Greenhouse, dry	Nov. 4,'11	-6	3	100	100	....
Greenhouse, wet	Nov. 4,'11	-6	3	100	100	....
KALE						
Out of doors, coldframe	Dec. 8,'11	-6.5	2	50	50	....
Out of doors, bed	Dec. 8,'11	-6.5	3	0	0	....
Greenhouse, dry	Dec. 8,'11	-6.5	3	100	100	....
Greenhouse, wet	Dec. 8,'11	-6.5	3	100	100	....
LETTUCE						
Out of doors	Mar. 9,'13	-3.5	8	0	25	.900
Greenhouse	Mar. 9,'13	-3.5	9	83.3	100.0	.867
Out of doors	Mar. 29,'13	-5	18	0	27.7	.900
Greenhouse	Mar. 29,'13	-5	16	68.7	93.7	.867
Out of doors	Apr. 30,'13	-3.5	24	0	33.3	.920
Greenhouse	Apr. 30,'13	-3.5	32	18	48	.740
Average, lettuce out of doors				0.0	28.7	.907
Average, lettuce greenhouse				56.6	80.1	.825

Depressions were not determined for each day's freezing on account of the limited number of plants, but depressions taken of other lots grown under the same conditions show similar results. Thus a set taken January 6, 1912, showed the following depressions: Plants grown out of doors, depression, 1.470; plants grown in the greenhouse with limited water supply, depression, 1.035; plants grown in the greenhouse with abundant water supply, depression, .990. Here again increased sap density is accompanied by greater hardiness, and in this case the plants with the greatest density are also the ones which grew most rapidly.

In all of these cases any treatments that increased the density of the sap lowered the killing temperature. It should be said, however, that in most cases where the density of the sap has been increased, the growth of the plants has been checked so we can not say positively that a treatment has increased the hardiness, due to the density of the sap, since it could probably be due to the smaller cells or some other differences in the conditions of the protoplasm. However, cabbage and kale were exceptions to this and actually grew more rapidly out of doors and yet had more dense sap and were more hardy. In order to test the effect of increased sap density on hardiness under conditions where this effect on growth would be eliminated, plants of tomato, cabbage, lettuce, kale and cowpeas were grown under like conditions. Then the plants were pulled, the roots washed clean and placed in sugar solutions and in potassium chloride and other solutions of varying strengths as shown in the table, with the results to be seen in the following table.

TABLE 7. SHOWING INFLUENCE OF ABSORBED SOLUTIONS ON HARDINESS.

Roots 24 hrs. in solutions of strength measured by freezing points given below	Date	Temperature	Number of Leaves	Percentage Killed	Percentage Killed and Partly Killed	Depression
TOMATOES						
Glucose (.460).........	July 27,'11	-3.0	84	63.0	67.6	0.785
Cane Sugar (.435).....	July 27,'11	-3.0	60	83.3	88.3	0.925
Glycerine (.430).......	July 27,'11	-3.0	70	72.8	88.5	1.070
Potassium Nitrate (.463)..............	July 27,'11	-3.0	57	100.0	100.0	0.880
Water................	July 27,'11	-3.0	65	100.0	100.0	0.700
Glucose (.460).........	July 27,'11	-2.0	60	0.0	0.0	0.785
Cane Sugar (.435).....	July 27,'11	-2.0	57	24.5	56.1	0.925
Glycerine (.430).......	July 27,'11	-2.0	44	50.0	53.6	1.070
Potassium Nitrate (.463)..............	July 27,'11	-2.0	46	60.8	73.9	0.880
Water................	July 27,'11	-2.0	48	62.5	72.9	0.700
Glucose (.460).........	July 28,'11	-3.5	48	91.6	95.8	0.785
Cane Sugar (.435).....	July 28,'11	-3.5	47	89.3	95.7	0.925
Glycerine (.430).......	July 28,'11	-3.5	55	94.5	100.0	1.070
Potassium Nitrate (.463)..............	July 28,'11	-3.5	53	98.1	100.0	0.880
Water................	July 28,'11	-3.5	43	76.7	100.0	0.70
Glucose (.460).........	July 28,'11	-2.5	47	59.5	70.0	0.785
Cane Sugar (.435).....	July 28,'11	-2.5	58	13.8	17.2	0.925
Glycerine (.430).......	July 28,'11	-2.5	52	9.6	44.2	1.070
Potassium Nitrate (.463)..............	July 28,'11	-2.5	43	83.7	100.0	0.880
Water................	July 28,'11	-2.5	42	11.9	16.6	0.700
Glucose (.460).........	July 28,'11	-3	33	69.7	69.7	0.785
Cane Sugar (.435).....	July 28,'11	-3	37	18.9	35.1	0.925
Glycerine (.430).......	July 28,'11	-3	44	61.3	61.3	1.070
Potassium Nitrate (.463)..............	July 28,'11	-3	46	100.0	100.0	0.880
Water................	July 28,'11	-3	42	66.6	66.6	0.700
Glucose (.460), average..........................				56.8	60.6	0.785
Cane Sugar (.435), average......................				45.9	58.5	0.925
Glycerine (.430), average.......................				57.6	69.5	1.070
Potassium Nitrate (.463), average................				88.5	94.6	0.880
Water, average................................				63.5	71.2	0.700

Roots 24 hrs. in solutions of strength measured by freezing points given below	Date	Temperature	Number of Leaves	Percentage Killed	Percentage Killed and Partly Killed	Depression
TOMATOES Treated 18 hrs.						
Water	June 28,'13	-2.5	20	50.0	65.0	.698
Potassium Chloride (.775)	June 28,'13	-2.5	19	0.0	0.0	1.103
Ammonium Chloride (.360)	June 28,'13	-2.5	15	66.7	93.3	.863
Glycerine (2.820)	June 28,'13	-2.5	27	0.0	0.0	2.083
Water	June 28,'13	-3.0	16	100.0	100.0	.698
Potassium Chloride (.775)	June 28,'13	-3.0	17	0.0	35.3	1.103
Ammonium Chloride (.360)	June 28,'13	-3.0	16	68.7	77.4	.863
Cane Sugar (.677)	June 28,'13	-3.0	30	53.3	76.6	1.053
CABBAGE						
Cane Sugar (0.77)	Aug. 24,'11	-4.0	3	100.0	100.0	1.230
Glucose (0.44)	Aug. 24,'11	-4.0	3	100.0	100.0	1.190
Glycerine (0.66)	Aug. 24,'11	-4.0	3	66.6	66.6	1.270
Potassium Chloride (0.73)	Aug. 24,'11	-4.0	3	0.0	0.0	1.525
Ammonium Chloride (0.51)	Aug. 24,'11	-4.0	3	100.0	100.0	1.195
Water	Aug. 24,'11	-4.0	3	66.6	66.6	1.080
Cane Sugar (0.77)	Aug. 26,'11	-3.5	3	66.6	66.6	1.230
Glucose (0.44)	Aug. 26,'11	-3.5	3	66.6	66.6	1.190
Glycerine (0.66)	Aug. 26,'11	-3.5	3	66.6	66.6	1.270
Potassium Chloride (0.73)	Aug. 26,'11	-3.5	3	0.0	0.0	1.525
Ammonium Chloride (0.51)	Aug. 26,'11	-3.5	3	100.0	100.0	1.195
Water	Aug. 26,'11	-3.5	3	100.0	100.0	1.080
Cane Sugar (0.77)	Aug. 31,'11	-5.5	3	66.6	66.6	1.230
Glucose (0.44)	Aug. 31,'11	-5.5	3	33.3	33.3	1.190
Glycerine (0.66)	Aug. 31,'11	-5.5	3	0.0	0.0	1.270
Potassium Chloride (0.73)	Aug. 31,'11	-5.5	3	0.0	0.0	1.525
Ammonium Chloride (0.51)	Aug. 31,'11	-5.5	3	66.6	66.6	1.195
Water	Aug. 31,'11	-5.5	3	0.0	0.0	1.080
Cane Sugar (0.77), average				77.7	77.7	1.230
Glucose (0.44), average				66.6	66.6	1.190
Glycerine (0.66), average				44.4	44.4	1.270
Potassium Chloride (0.73), average				0.0	0.0	1.525
Ammonium Chloride (0.51), average				88.8	88.8	1.195
Water, average				55.5	55.5	1.080

Roots 24 hrs. in solutions of strength measured by freezing points given below	Date	Temperature	Number of Leaves	Percentage Killed	Percentage Killed and Partly Killed	Depression
CABBAGE (later freezing)						
No treatment	July 1,'13	-4.0	5	80.0	100.0	.780
Potassium Chloride (.775)	July 1,'13	-4.0	5	40.0	100.0	1.145
Glycerine (2.82)	July 1,'13	-4.0	5	20.0	80.0	1.780
Ammonium Chloride (.360)	July 1,'13	-4.0	5	100.0	100.0	.950
COWPEAS						
Cane Sugar (1.570)	Sept. 1,'11	-3.0	3	0.0	0.0	1.230
Glucose (1.740)	Sept. 1,'11	-3.0	3	100.0	100.0	1.250
Glycerine (1.575)	Sept. 1,'11	-3.0	3	0.0	0.0	1.160
Potassium Chloride (0.730)	Sept. 1,'11	-3.0	3	100.0	100.0	1.130
Ammonium Chloride (0.725)	Sept. 1,'11	-3.0	3	66.6	66.6	1.140
Water	Sept. 1,'11	-3.0	3	33.3	33.3	.870
Cane Sugar (1.570)	Sept. 9,'11	-3.0	3	0.0	0.0	1.230
Glucose (1.740)	Sept. 9,'11	-3.0	3	33.3	66.6	1.250
Glycerine (1.575)	Sept. 9,'11	-3.0	3	0.0	0.0	1.160
Potassium Chloride (0.730)	Sept. 9,'11	-3.0	3	0.0	0.0	1.130
Ammonium Chloride (0.725)	Sept. 9,'11	-3.0	3	33.3	100.0	1.140
Water	Sept. 9,'11	-3.0	3	100.0	100.0	.870
Cane Sugar (1.570)	Sept. 9,'11	-3.5	3	0.0	0.0	1.230
Glucose (1.740)	Sept. 9,'11	-3.5	3	66.6	66.6	1.250
Glycerine (1.575)	Sept. 9,'11	-3.5	3	0.0	0.0	1.160
Potassium Chloride (0.730)	Sept. 9,'11	-3.5	3	66.6	66.6	1.130
Ammonium Chloride (0.725)	Sept. 9,'11	-3.5	3	66.6	66.6	1.140
Water	Sept. 9,'11	-3.5	3	33.3	33.3	.870
Cane Sugar (1.570)	Aug. 29,'11	-3	3	0.0	0.0	1.230
Glucose (1.740)	Aug. 29,'11	-3	3	0.0	0.0	1.250
Glycerine (1.575)	Aug. 29,'11	-3	3	0.0	0.0	1.160
Potassium Chloride (0.730)	Aug. 29,'11	-3.0	3	100.0	100.0	1.130
Ammonium Chloride (0.725)	Aug. 29,'11	-3.0	3	0.0	0.0	1.140
Water	Aug. 29,'11	-3.0	3	100.0	100.0	.870
Cane Sugar (1.570), average				0.0	0.0	1.230
Glucose (1.740), average				49.9	58.3	1.250
Glycerine (1.575), average				0.0	0.0	1.160
Potassium Chloride (0.730), average				66.6	66.6	1.130
Ammonium Chloride (0.725), average				41.6	58.3	1.140
Water, average				66.6	66.6	.870

Roots 24 hrs. in solutions of strength measured by freezing points given below	Date	Temperature	Number of Leaves	Percentage Killed	Percentage Killed and Partly Killed	Depression
KALE					Percentage total leaf surface killed	
Cane Sugar (.677).....	June 25,'13	-3.0	5	0.0	45.0	.947
Glycerine (2.820)......	June 25,'13	-3.0	5	20.0	35.0	1.595
Potassium Chloride (.775).............	June 25,'13	-3.0	5	60.0	80.0	.967
Ammonium Chloride (.360).............	June 25,'13	-3.0	5	80.0	95.0	.775
Water...............	June 25,'13	-3.0	5	80.0	93.0	.677
Cane Sugar (.677).....	July 9,'13	-1.5	5	40.0	45.0	1.150
Glycerine (2.820)......	July 9,'13	-1.5	5	0.0	10.0	1.980
Potassium Chloride (.775).............	July 9,'13	-1.5	5	0.0	20.0	.980
Ammonium Chloride (.360).............	July 9,'13	-1.5	5	60.0	80.0	.895
Water...............	July 9,'13	-1.5	5	60.0	75.0	.830
LETTUCE						
Cane Sugar (.677).....	July 2,'13	-2.5	5	0.0	35.0	.578
Glycerine (2.820)......	July 2,'13	-2.5	5	0.0	30.0	1.168
Potassium Chloride (.775).............	July 2,'13	-2.5	5	20.0	60.0	.655
Ammonium Chloride (.360).............	July 2,'13	-2.5	5	40.0	70.0	.550
Water...............	July 2,'13	-2.5	5	40.0	90.0	.430
Cane Sugar (.677).....	July 2,'13	-3.5	5	20.0	85.0	.578
Glycerine (2.820)......	July 2,'13	-3.5	5	0.0	55.0	1.168
Potassium Chloride (.775).............	July 2,'13	-3.5	5	40.0	65.0	.655
Ammonium Chloride (.360).............	July 2,'13	-3.5	5	60.0	90.0	.550
Water...............	July 2,'13	-3.5	5	60.0	90.0	.430
Cane Sugar (.677).....	July 8,'13	-3.0	5	0.0	25.0	.652
Glycerine (2.820)......	July 8,'13	-3.0	5	0.0	35.0	.728
Potassium Chloride (.775).............	July 8,'13	-3.0	5	0.0	55.0	.690
Ammonium Chloride (.360).............	July 8,'13	-3.0	5	60.0	90.0	.690
Water...............	July 8,'13	-3.0	5	20.0	65.0	.597

Here again the hardiness has been increased by increasing the density of the sap. Of course it should be admitted that even here there is a possibility that some actual change in the protoplasm has taken place by treating it with these solutions. Glycerine has been most effective in increasing the sap density of the tissue and in increasing the resistance to cold. It is interesting to observe that in the case of cabbage, the sap density and the hardiness were more greatly increased with salts like potassium chloride than with cane sugar, while in the case of tomatoes, sugar was taken up in larger quantities and caused a greater increase in hardiness.

According to the theory of Gorke, if killing is due to the salting out of proteids, we should expect the taking up of sugar to increase the hardiness but should not expect that result to follow the taking up of salts. The salts that most readily precipitate certain proteids are ammonium sulphate and zinc sulphate. When roots of tomato plants were kept for twenty-four hours in solutions of a molecular concentration as great as those used in the table above, the hardiness of the leaves was not reduced, and zinc sulphate seemed to increase the hardiness. These results are not in accord with Gorke's theory. Potassium nitrate does not increase the hardiness as other substances do. Thus tomato plants with their roots kept in potassium nitrate solution of about the same molecular concentration as the solutions used above, seemed to be killed more easily than when the roots were kept in pure water, and corn plants so treated certainly were killed more easily. This lack of protective action is probably due to the high eutectic point of the potassium nitrate since it would precipitate out before the killing temperature of the tissue is reached.

Apple and peach blossoms were cut from the twigs in such a way that a considerable area of cortex and sap wood adhered to the stem, and these were inserted in solutions of varying strengths of sugar and glycerine and later frozen. The following table gives the results:

TABLE 8. SHOWING INFLUENCE OF ABSORBED SOLUTIONS ON HARDINESS OF YOUNG FRUITS.

Kind of Fruit	Treatment	Date	Temperature	Number of Fruits	Percentage Killed
Rice's Seedling peach blossoms	Fresh	Apr. 15,'11	-3	43	70.0
Rice's Seedling peach blossoms	Cane sugar (2.250)	Apr. 15,'11	-3	34	3.0
Rice's Seedling peach blossoms	Glycerine (2.560)	Apr. 15,'11	-3	45	22.0
Rice's Seedling peach blossoms	Water	Apr. 15,'11	-3	50	100.0
Rice's Seedling peach blossoms	Cane sugar (2.250)	Apr. 20,'11	-3	13	61.0
Rice's Seedling peach blossoms	Glycerine (2.560)	Apr. 20,'11	-3	22	36.0
Rice's Seedling peach blossoms	Water	Apr. 20,'11	-3	15	66.0
Rice's Seedling peach blossoms, petals just fallen	Cane sugar (2.250)	Apr. 20,'11	-3	24	81.0
Rice's Seedling peach blossoms, petals just fallen	Glycerine (2.560)	Apr. 20,'11	-3	21	81.0
Rice's Seedling peach blossoms, petals just fallen	Water	Apr. 20,'11	-3	13	58.0
Peaches in husk	Fresh	May 4,'11	-3	..	12.2
Peaches in husk	Cane sugar (2.250)	May 4,'11	-3	..	8.7
Peaches in husk	Glycerine (2.560)	May 4,'11	-3	..	6.0
Peaches in husk	Water	May 4,'11	-3	..	70.0
Peaches 2-5 in. in dia.	Fresh	May 11,'11	-3.9	21	24.0
Peaches 2-5 in. in dia.	Cane sugar (2.250)	May 11,'11	-3.9	20	35.0
Peaches 2-5 in. in dia.	Glycerine (2.560)	May 11,'11	-3.9	25	4.0
Peaches 2-5 in. in dia.	Water	May 11,'11	-3.9	18	38.0
Apple buds showing pink	Canesugar (2.250)	Apr. 24,'11	-3	31	61.0
Apple buds showing pink	Glycerine (2.560)	Apr. 24,'11	-3	30	13.0
Apple buds showing pink	Water	Apr. 24,'11	-3	25	96.0
Apple buds nearly open	Fresh	Apr. 24,'11	-3	30	100.0
Apple buds nearly open	Cane sugar (2.250)	Apr. 24,'11	-3	40	60.0
Apple buds nearly open	Glycerine (2.560)	Apr. 24,'11	-3	32	0.0
Apple buds nearly open	Water	Apr. 24,'11	-3	45	100.0
Apple buds partly open	Cane sugar (2.250)	Apr. 26,'11	-3	34	3.0
Apple buds partly open	Glycerine (2.560)	Apr. 26,'11	-3	34	61.0

Kind of Fruit	Treatment	Date	Temperature	Number of Fruits	Percentage Killed
Apple buds partly open	Water......	Apr. 26,'11	-3	23	100.0
Apple blossoms open...	Fresh.......	Apr. 26,'11	-3	27	4.0
Apple blossoms open...	Cane sugar (2.250)....	Apr. 26,'11	-3	50	0.0
Apple blossoms open...	Glycerine (2.560)....	Apr. 26,'11	-3	50	14.0
Apple blossoms open...	Water......	Apr. 26,'11	-3	37	92.0
Apple blossoms, petals just fallen...........	Fresh.......	May 4,'11	-3	28	36.0
Apple blossoms, petals just fallen...........	Cane sugar (2.250)....	May 4,'11	-3	50	4.0
Apple blossoms, petals just fallen...........	Glycerine (2.560)....	May 4,'11	-3	44	4.0
Apple blossoms, petals just fallen...........	Water......	May 4,'11	-3	43	72.0
Apples just after petals fall................	Fresh......	May 11,'11	-3.9	58	35.0
Apples just after petals fall................	Cane sugar (2.250)....	May 11,'11	-3.9	83	9.6
Apples just after petals fall................	Glycerine (2.560)....	May 11,'11	-3.9	76	3.0
Apples just after petals fall................	Water......	May 11,'11	-3.9	66	79.0
Apples 1-3 in. in dia....	Fresh.......	May 11,'11	-3.9	17	41.0
Apples 1-3 in. in dia....	Cane sugar (2.250)....	May 11,'11	-3.9	27	20.0
Apples 1-3 in. in dia....	Glycerine (2.560)....	May 11,'11	-3.9	31	6.4
Apples 1-3 in. in dia....	Water......	May 11,'11	-3.9	28	100.0
Wild Goose plums......	Cane sugar (2.250)....	May 11,'11	-3.9	25	4.0
Wild Goose plums......	Glycerine (2.560)....	May 11,'11	-3.9	25	0.0
Wild Goose plums......	Water......	May 11,'11	-3.9	21	16.0
Average, Cane sugar (2.50)........					26.9
Average, Glycerine (2.560)........					19.2
Average, Water........					75.9

It will be seen again that absorbing the solutions increased the resistance to cold. Depressions were not taken because it would require too many fruits treated in this way. However, it is safe to assume that the sap density was increased as it certainly was with the fruits used for the next table.

During the spring of 1913, twigs containing peaches, apples and cherries were placed with the ends in glycerine solution, sugar

solution and in pure water. These fruits absorbed the solutions readily as the depression data following the table will show. The following table gives the result of freezing these fruits:

TABLE 9. SHOWING EFFECT OF ABSORBED SOLUTIONS ON HARDINESS OF BLOSSOMS AND YOUNG FRUITS ON TWIGS.

Kind of Fruit	Treatment	Date	Temperature	Number of Fruits	Percentage Killed
Twigs containing very young Rareripe peaches	Water 23 hrs.	Apr. 28,'13	–5	56	55.3
Twigs containing very young Rareripe peaches	20% Cane sugar 23 hrs.	Apr. 28,'13	–5	77	29.7
Twigs containing very young Rareripe peaches	10% Glycerine 23 hrs.	Apr. 28,'13	–5	51	11.8
Twigs containing very young Rareripe peaches	Fresh from tree	Apr. 28,'13	–5	69	49.3
Twigs containing young Hiley peaches	10% Glycerine 20 hrs.	May 1,'13	–4	65	1.5
Twigs containing young Hiley peaches	Fresh from tree	May 1,'13	–4	76	1.3
Twigs containing Lewis peaches	Water 21 hrs.	May 17,'13	–4	22	45.5
Twigs containing Lewis peaches	10% Glycerine 21 hrs.	May 17,'13	–4	35	11.4
Twigs containing Lewis peaches	Wilted 6 hrs.	May 17,'13	–4	22	45.5
Twigs containing Lewis peaches	Fresh from tree	May 17,'13	–4	23	43.5
Twigs containing Bernard peaches	10% Glycerine 22 hrs.	May 21,'13	–4.2	51	13.7
Twigs containing Bernard peaches	Wilted 5 hrs.	May 21,'13	–4.2	53	69.8
Twigs containing Bernard peaches	Fresh from tree	May 21,'13	–4.2	34	61.8
Twigs containing open Rome Beauty apple blossoms	20% Cane sugar solution 20 hrs.	May 1,'13	–4	96	15.6
Twigs containing open Rome Beauty apple blossoms	10% Glycerine 20 hrs.	May 1,'13	–4	108	13.8
Twigs containing open Rome Beauty apple blossoms	Fresh from tree	May 1,'13	–4	83	40.0

Kind of Fruit	Treatment	Date	Temperature	Number of Fruits	Percentage Killed
Twigs containing Jonathan apples	Water 21 hrs	May 17,'13	−4	27	70.4
Twigs containing Jonathan apples	10% Glycerine 21 hrs	May 17,'13	−4	32	43.8
Twigs containing Jonathan apples	Wilted 6 hrs	May 17,'13	−4	37	86.5
Twigs containing Jonathan apples	Fresh from tree	May 17,'13	−4	19	68.4
Twigs containing Dyehouse cherries	Water 21 hrs	May 17,'13	−4	42	30.9
Twigs containing Dyehouse cherries	10% Glycerine 21 hrs	May 17,'13	−4	43	13.9
Twigs containing Dyehouse cherries	Wilted 6 hrs	May 17,'13	−4	36	48.8
Twigs containing Dyehouse cherries	Fresh from tree	May 17,'13	−4	15	66.6
Twigs containing Dyehouse cherries	10% Glycerine 22 hrs	May 21,'13	−4.2	39	5.1
Twigs containing Dyehouse cherries	Wilted 5 hrs	May 21,'13	−4.2	56	21.4
Twigs containing Dyehouse cherries	Fresh from trees	May 21,'13	−4.2	38	39.5
Average percentage killed, fresh					48.8
Average percentage killed, glycerine					14.4

Since it requires a large number of blooms or young fruits to furnish sap for a freezing point determination, only one such determination was made. This resulted as follows, using fruits treated just as they were for freezing:

	Depression degrees
Cherries fresh from tree	0.905
Cherries from twigs with ends in glycerine sixteen hours	1.180
Cherries wilted five hours	1.075
Peaches fresh from tree	.965
Peaches from twigs with ends in glycerine sixteen hours	1.230
Peaches wilted five hours	1.085
Apples from twigs with ends in glycerine thirty hours	1.408
Apples from twigs with ends in water thirty hours	1.335
Apples from twigs with ends in cane sugar thirty hours	1.530
Apples from twigs with ends in glycerine forty-eight hours	1.417
Apples from twigs with ends in water forty-eight hours	1.030
Apples from twigs with ends in cane sugar forty-eight hours	1.160

It seems then practically certain that one is justified in assuming that the fruits in the above freezing table had their osmotic strength increased as much by taking up the glycerine and sugar solutions as this depression data indicates. The fruits that had absorbed the glycerine were apparently fully turgid while the wilted fruits were very flaccid. It is certain that wilting could have had little part in increasing the sap density of the fruits absorbing the glycerine. It may be suggested by some that possibly the tissue could not absorb these rather strong solutions as rapidly as it could absorb water, so there might be some wilting to cause the greater hardiness attributed to the increased sap density. Observations were made on this point in all cases and rarely was there any signs of wilting in the frozen tissues referred to. In most cases, plants which were wilted until they were very limp before treating as described above were still less hardy than those absorbing the solutions. It is thus certain that the greater hardiness of the tissue absorbing the various solutions was not due to wilting. The effect of wilting on tissue is discussed later in this paper.

Reducing Sap Density by Shading. The sap density of leaves is known to increase from morning to afternoon. Leaves shaded usually have a lower sap density than those in the light. It was thought that this would be another good means of testing the effect of sap density on hardiness. The following plants (or twigs containing leaves) were shaded for twenty-four hours and taken for freezing in early afternoon along with plants under similar conditions, except that they were in full sunlight. The results are shown in Table 10:

TABLE 10. SHOWING EFFECT OF SHADING ON SAP DENSITY AND RESISTANCE TO FREEZING.

Material	Treatment	Date	Temperature	Number of Plants	Percentage All Killed	Percentage Total Leaf Area Killed	Depression
Cowpeas.......	Shaded....	June 14,'13	−4	3	0.0	90.0	.852
Cowpeas.......	Not shaded	June 14,'13	−4	2	100.0	100.0	.980
Cowpeas.......	Shaded....	June 14,'13	−3	3	0.0	90.0	.852
Cowpeas.......	Not shaded	June 14,'13	−3	3	0.0	22.0	.980
Cowpeas.......	Shaded....	June 17,'13	−3	3	66.6	66.6	.855
Cowpeas.......	Not shaded	June 17,'13	−3	4	25.0	81.2	.947

Material	Treatment	Date	Temperature	Number of Plants	Percentage All Killed	Percentage Total Leaf Area Killed	Depression
White corn.....	Shaded....	June 13,'13	-4	15	....	99.0	.728
White corn....	Not shaded	June 13,'13	-4	12	....	99.0	.888
Corn..........	Shaded....	June 17,'13	-3	7	18.8	55.0	.835
Corn..........	Not shaded	June 17,'13	-3	7	0.0	25.0	1.035
Tomato leaflets.	Shaded....	June 19,'13	-2	34	38.2	65.3	.708
Tomato leaflets.	Not shaded	June 19,'13	-2	51	0.0	0.0	.848
Tomato leaflets.	Shaded....	June 19,'13	-3.5	35	100.0	100.0	.708
Tomato leaflets.	Not shaded	June 19,'13	-3.5	36	47.2	63.9	.848
Tomato leaves..	Shaded....	June 25,'13	-4	6	50.0	87.0	.595
Tomato leaves..	Not shaded	June 25,'13	-4	5	40.0	55.0	.752
Kale leaves.....	Shaded....	June 25,'13	-3.5	5	100.0	100.0	.660
Kale leaves.....	Not shaded	June 25,'13	-3.5	5	40.0	70.0	.790
Lettuce leaves...	Shaded....	June 25,'13	-3.5	6	100.0	100.0	.490
Lettuce leaves..	Not shaded	June 25,'13	-3.5	6	100.0	100.0	.590
Lettuce leaflets.	Shaded....	June 21,'13	-2.8	13	23.0	50.0	.570
Lettuce leaflets.	Not shaded	June 21,'13	-2.8	17	0.0	1.4	.740
Lettuce leaflets.	Shaded....	June 21,'13	-4	18	100.0	100.0	.570
Lettuce leaflets.	Not shaded	June 21,'13	-4	17	41.1	66.1	.740
Red Rock Cabbage leaflets	Shaded....	June 20,'13	-3.5	14	0.0	19.6	.860
Red Rock Cabbage leaflets..	Not shaded	June 20,'13	-3.5	14	7.1	7.1	.955
Red Rock Cabbage leaflets..	Shaded....	June 20,'13	-4.5	15	53.3	83.3	.860
Red Rock Cabbage leaflets..	Not shaded	June 20,'13	-4.5	12	50.0	77.0	.955
Cabbage leaflets	Shaded....	June 25,'13	-3.5	36	52.8	77.7	.680
Cabbage leaflets	Not shaded	June 25,'13	-3.5	38	36.8	63.1	.875
Early Harvest apple twigs and leaves....	Shaded....	June 28,'13	-4	39	0.0	35.9	1.975
Early Harvest apple twigs and leaves....	Not shaded	June 28,'13	-4	42	0.0	6.8	2.438
Early Harvest apple twigs and leaves....	Shaded....	June 28,'13	-5	47	34.0	70.0	1.975
Early Harvest apple twigs and leaves...	Not shaded	June 28,'13	-5	50	0.0	48.5	2.438
Early Harvest apple twigs and leaves....	Shaded....	July 1,'13	-4	34	0.0	19.8	1.930
Early Harvest apple twigs and leaves....	Not shaded	July 1,'13	-4	40	0.0	11.2	2.252
Early Harvest apple twigs and leaves....	Shaded....	July 1,'13	-5.5	38	0.0	40.1	1.930

Material	Treatment	Date	Temperature	Number of Plants	Percentage All Killed	Percentage Total Leaf Area Killed	Depression
Early Harvest apple twigs and leaves....	Not shaded	July 1,'13	-5.5	46	0.0	16.3	2.252
Pear twigs and leaves.......	Shaded....	June 28,'13	-4	25	24.0	74.0	
Pear twigs and leaves.......	Not shaded	June 28,'13	-4	28	0.0	36.6	
Pear twigs and leaves.......	Shaded....	June 28,'13	-5	25	80.0	95.0	
Pear twigs and leaves.......	Not shaded	June 28,'13	-5	26	15.4	63.4	
Average, Shaded, excluding pears....................					33.5	71.01	.985
Average, Not shaded, excluding pears.................					30.9	48.61	1.173

In practically all cases the cortex, cambium and sap wood of the twigs were injured rather severely, and in all cases the injury was worse with the shaded twigs.

In the case of the pear twigs and leaves sufficient sap for depression determination could not be secured.

Material	Treatment	Date	Temperature	Number of Plants	Percentage All Killed	Percentage Total Leaf Area Killed	Depression
Labrusca grape leaves.......	Shaded 38 hours .	July 8,'13	-3	18	27.2	54.2	.695
Labrusca grape leaves.......	Not shaded	July 8,'13	-3	17	35.3	58.8	.733
Labrusca grape leaves........	Shaded 38 hours..	July 8,'13	-4.5	22	100.	100.	.695
Labrusca grape leaves.......	Not shaded	July 8,'13	-4.5	17	76.4	94.1	.733
Labrusca grape leaves.......	Shaded 22 hours..	July 10,'13	-3.5	10	0.0	2.5	.755
Labrusca grape leaves.......	Not shaded	July 10,'13	-3.5	10	0.0	0.0	.920
Labrusca grape leaves.......	Shaded 22 hours..	July 10,'13	-4.5	10	30.0	30.0	.755
Labrusca grape leaves.......	Not shaded	July 10,'13	-4.5	10	0.0	15.0	.920
Labrusca grape leaves.......	Shaded 22 hours..	July 11,'13	-4	10	10.0	25.0	.835
Labrusca grape leaves.......	Not shaded	July 11,'13	-4	10	0.0	17.5	1.085
Labrusca grape leaves.......	Shaded 22 hours..	July 11,'13	-5.5	10	60.0	80.0	.835
Labrusca grape leaves.......	Not shaded	July 11,'13	-5.5	10	40.0	52.5	1.085
Average, shaded..................................					34.53	48.61	.761
Average, not shaded..............................					25.29	39.65	.912

While the differences are not large, it will be seen that the sap density of the shaded plants is uniformly lower and the killing greater.

Ohlweiler[1] at the Missouri Botanical Garden seemed to find some relation between the density of the sap of different plant species and their resistance to cold. This is true especially in the case of the different species of magnolia, where the leaf structure of species with dense sap and of those with dilute sap is similar, so there would not be this influence involved to modify the results.

From the beginning of these experiments, observations have been made in autumn as to plants killed by the various early frosts and freezing point determinations were made from leaves of these to see if there is to be found any relation between hardiness and sap density. In the following table the plants are listed as nearly as could be determined according to hardiness, the most tender first, though it is certain that almost any of the plants could be changed two or three places in the succession and be as accurately placed in order of hardiness. The depressions are also given. The leaves for the depressions were all taken in the morning as soon as the dew was off so they would be equally turgid.

TABLE 11. SHOWING THE RELATIVE HARDINESS OF GROWING PLANTS COMPARED WITH THEIR RELATIVE SAP DENSITY.

Plant	Depression
Morning-Glory (Ipomoea purpurea)	.920
Coleus (C. Blumei)	.428
Sweet Potato (Ipomoea Batatas)	.96
Moon Vine (Ipomoea Bona-Nox)	.863
Watermelon (Citrullus vulgaris)	.882
Cantaloupe (Cucumis Melo)	.588
Cucumber (Cucumis sativus)	.585
Caladium (Colocasia antiquorum)	.745
Pumpkin (Cucurbita Pepo)	.785
Tomato (Lycopersicum esculentum)	.832
Lantana (L. Camara)	.962
Dahlia (Dahlia variabilis)	.711
Blue Salvia (Salvia patens)	1.025
Red Salvia (Salvia splendens)	.765
Rose Geranium (Pelargonium graveolens)	1.835
Geranium (Pelargonium Hortorum)	1.075
Eggplant (Solanum Melongena)	.805
Alternanthera (Telanthera versicolor)	1.058
Periwinkle (Vinca major)	1.20
Ageratum (A. conyzoides)	1.055
Chard (Beta vulgaris var. Cycla)	.805
Celery (Apium graveolens)	1.442

[1]23d. Anl. Rpt. Mo. Bot. Gard. 1912, pp. 101-31. (Bibl. 87).

Plant	Depression
Gaillardia (G. pulchella)	.803
Chrysanthemum (C. Sinense)	1.955
Sedum spectabile	.575
Dandelion (Taraxacum officinale)	.975
Dock (Rumex crispus)	.997
Verbena (V. hybrida)	1.093
Hollyhock (Althaea rosea)	1.130
Horse-radish (Cochlearia Armoracia)	1.125
California Poppy (Eschscholzia Californica)	1.198
Clover (Trifolium pratense)	1.290
Violet (Viola odorata)	1.225
Cabbage (Brassica oleracea)	1.115
Plantain (Plantago major)	1.380
Strawberry (Fragaria Chiloensis)	1.865

All these depressions were determined as late in autumn as it was possible to secure healthy tissue.

While it is evident that other factors than sap density influence the hardiness, yet it seems true that more of the very tender plants are found among those with slight depressions, and a majority of the most hardy among those with greater density. It is possible that if a larger list of plants were obtained, this might not be true.

All of these tests have been made with succulent plants that kill at a temperature a few degrees below the freezing point. It is true that some rather hardy plants like cabbage, kale, lettuce and garden peas have been influenced in their killing temperature as greatly as have plants like tomatoes and cowpeas that kill at a temperature but slightly below the freezing point. However, in case of winter wood, and buds that have developed great resistance to cold by some sort of change, the problem would perhaps be different. This experiment started with the idea that it might be possible to increase the hardiness of buds of the peach in winter by increasing the sap density through the use of fertilizers. Accordingly, plots of peach trees at Dixon, Missouri, were fertilized with potassium chloride at the rate of about 500 pounds to the acre, in the springs of 1907, 1908, and 1909. Plots receiving potassium chloride at the rate of a little more than 500 pounds to the acre during the seasons of 1906, 1907, 1908, and 1909, were located in the orchard of the Ozark Orchard Company at Goodman, Missouri; and plots receiving 480 pounds of potassium chloride to the acre, beginning March, 1910, were located with the Ozark Fruit Farm Company, Brandsville Missouri. Potassium was used in these experiments because some experiments indicate that it is more readily taken into the cell to become an osmotically active agent than most other mineral nutri-

ents. In these orchards we have had opportunity to observe the results following cold periods that killed all the buds, cold periods that killed nearly all of them, and cold periods that left a fair crop, but in no case has there been any apparent effect on hardiness resulting from the use of potassium as a fertilizer. Twigs were secured from these plots in winter, spring, and summer and the density of the sap of the cortex determined by expressing the sap, and determining its freezing point, and no difference in the density could be detected between the plots fertilized with potassium and those receiving no fertilizer. These determinations could not be made with sap from buds because it could not be secured in sufficient quantities.

If it were possible to increase the sap density by accumulation in the cell of potassium or other materials applied to the soil, it could possibly affect the killing temperature of the bloom or young fruits or young growth in spring, even if it should have no effect on the killing temperature of the buds in their dormant condition. C. Dussere[1] observed apparently a slightly greater hardiness of young grape shoots on vines that had been fertilized with potassium than on vines that were not so fertilized. However, analyses failed to show the presence of more potassium in the wood of those vines receiving potassium fertilizer than in the wood of those that had not received fertilizer.

It may be said that on our peach plots we have had occasion to observe the effect of spring frosts on the bloom, as well as the effect of winter cold on the buds and have failed to observe any difference due to application of potassium to the soil.

Briefly summerizing all our results with the relation of sap density to hardiness, we are safe in concluding that, at least in case of plants not in a resting condition, a large amount of dissolved material either in the sap within the cell or in a solution surrounding the cell, will protect the cell from injury due to low temperature, to some extent at least. The protection where plants take the material into the cell seems to be much less than where the material in solution surrounds the cell, if the work of Maximow is confirmed.

The practical means of increasing hardiness seem to be very limited. Withholding water from plants in a plant bed will check the growth and thus increase the sap density and the hardiness. It was thought possible that with such plants as cabbage which take up potassium salts readily, watering in the plant bed with a solution of such salts would tend to increase their hardiness. However, cabbage and tobacco plants growing in a hotbed soil watered for eighteen

[1]Bul. Soc. Sci. Nat. 5, ser 48 (1912) No. 176, pp. 393. (Bibl. No. 31).

days with a solution of potassium chloride ranging from 4.02 per cent normal at first to 16.08 per cent normal toward the last showed no increase in either sap density or hardiness over that of plants not so treated. It is only in sand cultures that we have been able to increase the sap density of plants by watering them with solutions.

If freezing to death results from too complete withdrawal of water from the protoplasm, then, even with winter buds and wood, if the sap density could be increased with some material that stays in solution at temperatures lower than that at which the tissue kills, it would hold more water in solution and thus lower the temperature at which a killing degree of desiccation is reached. Müller-Thurgau's measurements showed that a very large percentage of the water in plant tissue is in the form of ice. In case of winter resting tissue very little water can be left unfrozen at a killing temperature. If freezing to death of plant tissue results from desiccation, then very small quantities of water must be sufficient to protect the protoplasm in case of the more hardy plants. Some writers hold that since some plants continue to live after nearly all the water is frozen out, desiccation of the protoplasm can not be the explanation of death from low temperatures. Others seem to hold the opinion that the protective action of the sap solute ends at the freezing point of the sap. It should be remembered that so long as the temperature is above the eutectic point of any of the sap solute, there will be some water present in the liquid state. The number of degrees which the killing temperature is lowered by an increase in sap density should be greater with plants that kill at the lower temperatures. Thus in case of a solution containing a gram molecule of a non-electrolyte in a liter of water, the freezing point is -1.86° C. In case of a solution with one-half of a gram molecule to a liter of water, the freezing point would be -0.93° C. The following figures would evidently be approximately true:

Temperature	Fraction of water unfrozen, gram-molecule, in a liter of water	Fraction of water unfrozen, one-half a gram-molecule, in a liter of water
-0.93° C.	all	all
-1.86° C.	all	1/2
-3.72° C.	1/2	1/4
-7.44° C.	1/4	1/8
-14.88° C.	1/8	1/16
-29.76° C.	1/16	1/32

This is, of course, assuming that the eutectic point of the solution is below these temperatures. It also assumes that the freezing point is lowered exactly in proportion to the molar concentration of the solution; that is, if there be four gram molecules in a liter of water, the freezing point should be four times -1.86° C. This is probably not quite true but the difference is so slight that it may be ignored here. It will thus be seen that with a solution in which there is a gram molecule to a liter of water of a solute that stays in solution below -29.76° C., there would be as much water unfrozen at -14.88° C., as there would be at -29.76° C., if the molar concentration is only half as great.

Maximow concludes that the protective action of the material he used was greater than could be explained by the depression of the freezing point of the sap. He may not have considered the above facts. Another fact should be considered. With the plants Maximow used, possibly a large percentage of the sap solute crystallized out at temperatures considerably above the minimum temperatures that he used. Maximow used as a protective substance a solution of equal density with the plant sap and with a low eutectic point, then at a temperature of say -10° C., it would be considerably more dense than the plant sap from which crystallization had taken place. While theoretically the protective action of increased density should be greater with plants that kill at a rather low temperature like winter buds and wood, we have found no way to demonstrate such protective action with such tissue. The only means of increasing the sap density of such tissue that suggested itself to us was by applying fertilizers like potassium chloride to the soil and this method has not had that effect.

From the experience of Maximow and experience here with cabbage and other plants where the salts in solution have increased the resistance to cold as much as it was increased by organic compounds, and in some cases more, it seems that one is safe in concluding that killing from cold is more likely a mechanical injury due to the withdrawal of water from the protoplasmic membrane than an injury resulting from the precipitation of proteids as suggested by Gorke, since an increase in the percentage of any mineral salt should tend to hasten the precipitation of proteids rather than reduce it.

It seemed that one good test of the theory of Gorke[1] would be to find whether or not a lower temperature is required to precipitate proteids from the sap of twigs as they increase in hardiness during

[1]Landw. Versuchs. Vol. 65, p. 149, 1906. (Bibl. No. 47).

early winter. It is known that from the time the leaves fall for at least one or one and one-half months, the cortex as well as the winter buds and the sap wood of deciduous trees (at least of peaches) continue to increase in hardiness. This Station made an effort to determine whether this increase in hardiness might not be due to such a change in the composition of proteids that they would tend to remain in solution at lower temperatures. Consequently twigs were gathered on the dates shown in the following table, beginning before leaf fall. Large quantities of cortex sap were expressed. After pouring back and forth to insure a uniform solution, one-half of this sap was frozen at the temperatures shown in the table, a temperature that would at that time kill the cortex and practically all other tissue of the twig. The other half was kept in an ice box until the freezing of the other sap was complete, then both were taken to the Department of Agricultural Chemistry for proteid analysis, the frozen sap being thawed on the filter except when otherwise stated in the tables. The analysis was by the following plan, kindly furnished by the Department of Agricultural Chemistry:

KJELDAHL-GUMMING METHOD FOR ESTIMATION OF NITROGEN.

"Weigh out accurately 4-6 grams of the sap by difference, place in 500 c. c. Kjeldahl flask, add 0.7 gram of mercury and 25 c. c. of sulphuric acid, heat for a few minutes until frothing ceases, add 7 grams of potassium sulphate and digest over a flame until clear, cool; wash down the neck of the flask with distilled water, heat again one hour until water is expelled. Cool and dilute with water until flask is 2 / 3 full, add a piece of zinc and a piece of paraffin and 80 c. c. of alkaline solution containing 500 grams potassium sulphide and 18 kilos sodium hydroxide in 40 liters of the solution. Distil into standard hydrochloric acid and titrate back with standard ammonium hydroxide, using cochineal as indicator". The factor 6.25 was used in reducing nitrogen reading to proteid readings.

Twigs of apple, peach, pear and plum were used with results as shown in the following table:

TABLE 12. SHOWING PERCENTAGE OF PROTEIDS IN FROZEN AND UNFROZEN SAP FROM TISSUES OF APPLE, PEAR, PEACH AND PLUM.

Kind of Sap	Date	Temperature	Average per cent proteids. Sap unfrozen	Average per cent proteids. Sap frozen
Wealthy apple twigs......	Sept. 4,'11	-17	0.397	0.435
Wealthy apple twigs......	Oct. 2,'11	- 9.5	0.556	0.544
Elberta peach twigs.......	Sept. 4,'11	-17	1.488	1.894
Elberta peach twigs......	Oct. 2,'11	- 9.5	2.644	2.550
Elberta peach twigs.......	Oct. 16,'11	- 9.5	2.550	2.531
Elberta peach roots.......	Oct. 16,'11	- 9.5	1.563	1.563
Elberta peach twigs.......	Nov. 30,'11	- 9	2.050	2.100
Chabot plum twigs.......	Sept. 4,'11	-17	0.651	0.694
Chabot plum twigs.......	Oct. 2,'11	- 9.5	0.819	0.800
Kieffer pear twigs.........	Sept. 4,'11	-17	0.144	0.031
Kieffer pear twigs.........	Oct. 2,'11	- 9.5	0.406	0.375
Kieffer pear twigs.........	Oct. 16,'11	- 9.5	0.288	0.288
Kieffer pear roots.........	Oct. 16,'11	- 9.5	0.181	0.206
Kieffer pear twigs.........	Nov. 30,'11	- 9	0.350	0.375

In no case does there seem to be any conclusive indications that proteids were precipitated by temperatures low enough to kill the plant tissue. Since there was no precipitation from the sap of tender twigs in early autumn, sap was not taken from twigs later in the season.

Cabbage and other succulent plants grown in the greenhouse, some well watered, some under dry conditions and others grown out of doors, also well watered but under conditions where they would withstand lower temperatures than would those grown in the greenhouse, had each an abundance of sap expressed, half of it being frozen to a temperature that would kill those well watered in the greenhouse, but would not kill those grown out of doors. Samples of each of these frozen and unfrozen were analyzed for proteids, with the results shown in the following table:

TABLE 13. SHOWING PERCENTAGE OF PROTEIDS IN FROZEN AND UNFROZEN SAP FROM SUCCULENT PLANTS.

Kind of Sap	Date	Temperature	Average per cent proteids. Sap frozen.	Average per cent proteids. Sap unfrozen.
Cabbage greenhouse, dry soil	Apr. 8,'12	-3	0.975	1.069
Cabbage, greenhouse	Apr. 8,'12	-3	0.781	0.838
Cabbage, out-of-doors	Apr. 8,'12	-3	1.406	1.438
Cabbage sap, outside	Nov. 28,'11	-5	1.675	1.856
Cabbage, inside dry soil	Oct. 28,'11	-5	1.144	1.281
Cabbage, inside	Oct. 28,'11	-5	0.919	0.956
Tomato sap, greenhouse	Dec. 1,'11	-3.7	0.594	0.438
Tomato sap, greenhouse, dry soil	Dec. 1,'11	-3.7	1.313	1.444
Tomato sap, outside	Dec. 1,'11	-3.7	0.700	0.713
Pea sap, inside	Apr. 27,'12	-5	2.069	2.413
Pea sap, outside	Apr. 27,'12	-5	3.088	1.625
Lettuce, sap inside	Apr. 27,'12	-5	0.519	0.613
Lettuce sap, outside	Apr. 27,'12	-5	0.269	0.263
Kale, greenhouse	Dec. 16,'11	-6.2	1.744	1.831
Kale, outside	Dec. 16,'11	-6.2	1.963	1.994

In case of cabbage, kale, lettuce and peas there is some evidence of precipitation in case of the more tender greenhouse plants, but it is possible that the differences are within the range of experimental error.

In March, 1913, apple roots that had been growing in the greenhouse for sixty days had sap expressed, half of it frozen to a temperature that would kill them, the other half not frozen. At the same time sap was taken from roots that had been kept in cold storage at a temperature seldom varying from 32°F., with the following results:

TABLE 14. SHOWING PERCENTAGE OF PROTEIDS IN FROZEN AND UNFROZEN SAP FROM APPLE ROOTS.

Material	Treatment	Date	Percentage Nitrogen
Apple stock, cold storage	Not frozen	Mar. 14,'13	0.325
Apple stock, cold storage	Frozen	Mar. 14,'13	0.325
Apple stock, greenhouse	Not frozen	Mar. 14,'13	0.592
Apple stock, greenhouse	Frozen	Mar. 14,'13	0.548

In case of the greenhouse grown apple stock there seems to be slight evidence that proteids were precipitated by the low temperature. However, the difference is probably within the range of error. In these cases great care was taken to prevent any change in the soluble proteid content of the sap before analysis began. The unfrozen sap was immediately started for analysis, after being expressed. In all cases the frozen sap was thawed on filter paper so that little change could take place after the thawing.

From the above tables, we are safe in concluding that in the case of the cortex of twigs from fruit trees in autumn or early winter, precipitation of proteids plays no part in the killing since temperatures that will kill all the cortex will precipitate no proteids. In the case of some succulent growing plants there seems some evidence that a killing temperature will precipitate a slight percentage of the soluble proteids present, but since increasing the amount of salts present that are supposed to precipitate the proteids increases instead of decreasing the resistance to low temperature, we are probably safe in concluding that precipitation of proteids does not explain freezing to death.

OTHER FEATURES THAT INFLUENCE THE FREEZING TO DEATH OF PLANTS.

Rate of Thawing. The effect of the rate of thawing on the killing from cold has been discussed previously with reference to the works of Müller-Thurgau,[1] Molisch,[2] and Sachs.[3] However, it is not out of place to discuss it briefly as one influence to be dealt with in the killing of certain plants from cold. As mentioned before, Müller-Thurgau and Molisch found only mature fruits and leaves of Agava Americana to be affected by the rate of thawing. Practically all plants used in freezing experiments to be reported in this paper have been tested with reference to the effect of rapid thawing, particularly because of the effect such thawing would have on the results with other experiments. The following table gives the results with peach fruit buds that were thawed slowly and rapidly:

[1]Landw. Jahrb. Vol. 15, p. 453, 1886. (Bibl. No. 78).

[2]Untersuchung über das Erfrieren, etc. Book, 1897. (Bibl. No. 75).

[3]Ber. u. d. Ver. d. Kon. Sachs. Gesell. d. Wiss. zu. Leipzig, 1860, Vol. 12, pp. 1-50. (Bibl. No. 94).

TABLE 15. SHOWING THE EFFECT OF SLOW AND RAPID THAWING ON THE AMOUNT OF KILLING OF PEACH FRUIT BUDS.

Variety	Treatment	Date	Temperature	Number of Buds	Percentage Killed
Hills Chili..........	Thawed rapidly..	Jan. 21,'11	-21	178	40
Hills Chili..........	Thawed slowly..	Jan. 21,'11	-21	200	51.1
Hills Chili..........	Thawed rapidly..	Jan. 22,'11	-20.5	100	7.0
Hills Chili..........	Thawed slowly..	Jan. 22,'11	-20.5	100	23.0
Lewis..............	Thawed rapidly..	Feb. 9,'11	-20.2	100	7.0
Lewis..............	Thawed slowly..	Feb. 9,'11	-20.2	100	20.0
Elberta.............	Thawed rapidly..	Dec. 8,'11	-16	110	20.9
Elberta.............	Thawed slowly..	Dec. 8,'11	-16	100	8.0
Elberta.............	Thawed rapidly..	Dec. 13,'11	-16	75	94.6
Elberta.............	Thawed slowly..	Dec. 13,'11	-16	80	100.0
Rice's Seedling......	Thawed rapidly..	Mar. 24,'13	-16	129	72.2
Rice's Seedling......	Thawed slowly..	Mar. 24,'13	-16	130	84
Elberta.............	Thawed rapidly..	Mar. 24,'13	-16	95	95.8
Elberta.............	Thawed slowly..	Mar. 24,'13	-16	83	90.4
Average, Thawed rapidly					38.93
Average, Thawed slowly					53.61

The buds were thawed slowly by simply lifting the inner cylinder to which they were attached and seeing that the temperature was raised to four or five degrees above that to which they were lowered. In no case was it possible that the temperature could have gone back to the minimum temperature recorded, and usually twelve hours, sometimes slightly more, were required for the thawing.

Enough buds were frozen to justify a positive conclusion that rapid thawing does not influence the amount of killing.

The following table gives the results of slow and rapid thawing of young fruits:

TABLE 16. SHOWING THE EFFECT OF THE RATE OF THAWING ON FREEZING TO DEATH OF YOUNG FRUIT.

Kind of Fruit	Age of Fruit in days	Date	Manner of Thawing	Temperature	Number of Fruits	Percentage Killed
Lewis peach......	30	May 17,'13	Rapidly in room.....	-4	23	43.5
Lewis peach......	30	May 17,'13	Slowly in freezer....	-4	24	25.0
Early Bernard peach..........	35	May 21,'13	Rapidly in room.....	-4	34	61.8
Early Bernard peach..........	35	May 21,'13	Slowly in freezer....	-4	34	91.2
Elberta Seedling peach..........	38	May 24,'13	Rapidly in room.....	-4	21	61.9
Elberta Seedling peach..........	38	May 24,'13	Slowly in room.....	-4	30	30.0
Elberta Seedling peach..........	38	May 24,'13	Rapidly, fanned....	-4	25	44.0
Carman peach.. dia. 1 in........	44	May 31,'13	Rapidly in room.....	-4	20	40.0
Carman peach dia. 1 in........	44	May 31,'13	Rapidly in sun......	-4	20	45.0
Carman peach dia. 1 in........	44	May 31,'13	Rapidly, fanned....	-4	20	45.0
Carman peach dia. 1 in........	44	May 31,'13	Slowly in freezer....	-4	20	45.0
Waddell peach dia. 1¼ in......	52	June 6,'13	Rapidly in room.....	-4.5	22	81.9
Waddell peach dia. 1¼ in......	52	June 6,'13	Slowly in freezer....	-4.5	22	70.0
Waddell peach dia. 1¼ in......	52	June 6,'13	Rapidly, fanned....	-4.5	22	80.0
Seedling peach....	..	June 11,'13	Rapidly in room.....	-4.5	15	46.7
Seedling peach....	..	June 11,'13	Slowly in freezer....	-4.5	16	25.0
Jonathan apple....	23	May 17,'13	Rapidly in room.....	-4	19	68.4
Jonathan apple....	23	May 17,'13	Slowly in freezer....	-4	15	60.0
Jonathan apple....	30	May 24,'13	Rapidly in room.....	-4	23	56.5
Jonathan apple....	30	May 24,'13	Slowly in freezer....	-4	31	80.7
Jonathan apple....	30	May 24,'13	Rapidly, fanned....	-4	19	78.9
Salome apple......	..	June 11,'13	Rapidly in room.....	-4	15	46.7
Salome apple......	..	June 11,'13	Slowly in freezer....	-4	15	33.3
Dyehouse cherry..	..	May 17,'13	Rapidly in room.....	-4	15	66.7
Dyehouse cherry..	..	May 17,'13	Slowly in freezer....	-4	18	16.6
Dyehouse cherry..	..	May 21,'13	Rapidly in room.....	-4	38	39.5
Dyehouse cherry..	..	May 21,'13	Slowly in freezer....	-4	47	80.9
Average, Rapidly in room......................................						55.8
Average, Slowly in freezer......................................						50.7

The fruits were thawed slowly by removing some of the salt and ice from the freezer and if necessary lifting the lid to the freezer so the temperature inside would immediately cool to about one degree centigrade above that to which the fruits were run. This was done in order to be certain that the slowly thawing fruits did not suffer greater killing by being kept at the minimum temperature longer than the rapidly thawed fruits. Approximately three hours were required for succulent plants and fruits to thaw in this way. It is apparently certain that the rate of thawing has little to do with the amount of killing of young peaches and apples. Not enough cherries were tried to justify conclusions.

It will be seen in the table that some of the fruits were fanned in thawing. These fruits were taken in the frozen condition from the freezer and put at once in the current from an electric fan to see if rapid evaporation during thawing and shortly afterward influences the killing. The results indicate that it does not.

Results at this station from freezing ripe winter apples agree with those of Müller-Thurgau and Molisch that unless the temperature goes too low, slow thawing will greatly reduce the amount of killing. With the very young fruits, however, there is no indication that the rate of thawing influences the killing.

The following table gives the results of freezing apples in early July that ripen in September; pears that ripen in August and September, ripe Yellow Swan peaches and Elberta peaches that ripen about August 15th in Columbia, and Krummel October peaches which ripen in September in Columbia:

TABLE 16. SHOWING RELATIVE EFFECTS OF SLOW AND RAPID THAWING OF FROZEN GREEN FRUIT OF APPLE, PEAR, PEACH AND PLUM.

Material	Date	Temperature	Number of Fruits	Percentage of Fruits Showing Injury	Remarks
Jonathan apples, 1½ in. in diameter (Thawed rapidly)....	July 11,'13	−5	10	80	Seeds uninjured
Jonathan apples, 1½ in. in diameter (Thawed slowly).....	July 11,'13	−5	10	100	Seeds uninjured
Jonathan apples, half grown (Thawed rapidly)....	July 14,'13	−5	6	100	Slight injury
Jonathan apples, half grown (Thawed slowly).....	July 14,'13	−5	6	100	Slight injury
Jonathan apples, (Thawed rapidly)....	July 17,'13	−5	5	100	Slight injury
Jonathan apples, (Thawed slowly).....	July 17,'13	−5	5	100	Slight injury
Blenheim apples, ripe (Thawed rapidly)....	July 14,'13	−5	4	100	Slight injury
Blenheim apples, ripe (Thawed slowly).....	July 14,'13	−5	4	100	Slight injury
Duchess pear, 1½ in. in diameter (Thawed rapidly)....	July 11,'13	−5	10	70	Seeds of injured fruit dead
Duchess pear, 1½ in. in diameter.... (Thawed slowly)	July 11,'13	−5	10	60	Seeds of injured fruit dead
Tyson pear, half-grown (Thawed rapidly)....	July 14,'13	−5	4	100	Slight injury
Tyson pear, half-grown (Thawed slowly).....	July 14,'13	−5	4	100	Slight injury
Duchess pear, green (Thawed rapidly)....	July 17,'13	−5	5	100	Slight injury
Duchess pear, green (Thawed slowly).....	July 17,'13	−5	5	100	Slight injury
Krummel October peach (Thawed rapidly)....	July 12,'13	−5	10	100	Seeds of injured fruit killed
Krummel October peach (Thawed slowly).....	July 12,'13	−5	10	100	Flesh thawed in freezer little less injured

Material	Date	Temperature	Number of Fruits	Percentage of Fruits Showing Injury	Remarks
Elberta peach, green (Thawed rapidly)....	July 14,'13	-5	5	100	Slight injury
Elberta peach, green (Thawed slowly).....	July 14,'13	-5	5	100	Slight injury
Yellow Swan peach, ripe (Thawed rapidly)....	July 14,'13	-5	4	100	Slight injury
Yellow Swan peach, ripe (Thawed slowly).....	July 14,'13	-5	4	100	Slight injury
Elberta peach, green (Thawed rapidly)....	July 17,'13	-5	5	100	Injury slight
Elberta peach, green (Thawed slowly).....	July 17,'13	-5	5	100	Injury slight
Graves peach, ripe (Thawed rapidly)....	July 17,'13	-5	5	100	Injury slight
Graves peach, ripe (Thawed slowly) ...	July 17,'13	-5	5	100	Injury slight
Wild Goose plum, green (Thawed rapidly)....	July 14,'13	-5	5	80	Injury rather severe
Wild Goose plum, green (Thawed slowly).....	July 14,'13	-5	5	100	Injury rather severe
Wild Goose plum, ripe (Thawed rapidly)....	July 14,'13	-5	5	100	Injury rather severe
Wild Goose plum, ripe (Thawed slowly)	July 14,'13	-5	5	100	Injury rather severe
Average, green fruits rapidly thawed...............				93.6	
Average, green fruits slowly thawed...............				96.4	

Those fruits that were thawed slowly were thawed in the same manner as the young fruits in the previous table. They were thawed as slowly as it was possible to thaw them. Ice without salt was packed over the freezer and left over night. For those frozen July 14th, the temperature at 5:05 P. M. was -4.5° C; at 5:30 P. M., -3.5° C; at 5:45 P. M., -3° C, and at 6:30 A. M. the next day it was 9.5° C. The temperature rise for the other freezings was approximately the same. The ice was all out of the fruits thawed rapidly in a warm

room in a few minutes. In no case was there any evidence that the rate of thawing affected the amount of injury to the unripe fruit, or even to the partially ripe Yellow Swan peaches. It seems probable that slow thawing affects the amount of injury to fruits only in case of ripe apples and pears.

The following table gives the results of slow and rapid thawing of some garden plants:

TABLE. 17. SHOWING THE EFFECT OF SLOW AND RAPID THAWING ON LEAVES AND STEMS OF GROWING PLANTS.

Material	Manner of Thawing	Date	Temperature	Number of Leaves	Percentage all Killed	Percentage Total Surface Killed
Cowpeas.........	Rapidly in room.	May 28,'13	-3.8	12	25	
Cowpeas.........	Slowly in freezer	May 28,'13	-3.8	26	100	
Cowpeas.........	Rapidly in sun..	May 28,'13	-3.8	25	100	
Cowpeas.........	Rapidly in room.	June 14,'13	-4	3	100	100
Cowpeas.........	Slowly in freezer.	June 14,'13	-4	3	..	90
Lettuce..........	Rapidly in room.	May 7,'13	-4	27	22.2	37
Lettuce..........	Slowly in freezer.	May 7,'13	-4	20	5.0	13
Lettuce..........	Rapidly in room.	May 13,'13	-4	4	..	90
Lettuce..........	Slowly in freezer.	May 13,'13	-4	3	..	50
Lettuce (Black Seeded Simpson)	Rapidly in room.	June 12,'13	-4	9	66.6	92
Lettuce (Black Seeded Simpson)	Slowly in freezer.	June 12,'13	-4	11	36.6	50
Lettuce (Black Seeded Simpson)	Rapidly in room.	June 12,'13	-4	10	90.0	97.5
Lettuce (Black Seeded Simpson)	Slowly in freezer.	June 12,'13	-4	10	90.0	97.5
Kale............	Rapidly in room.	May 15,'13	-5	6	16.6	20.8
Kale............	Slowly in freezer.	May 15,'13	-5	5	0.0	0.0
Kale............	Rapidly in room.	June 28,'13	-3.5	5	100.0	100.0
Kale............	Slowly in freezer.	June 28,'13	-3.5	5	100.0	100.0
Kale,...........	Rapidly, fanned.	June 28,'13	-3.5	5	100.0	100.0
Kale............	Rapidly in room.	July 3,'13	-3.5	5	80.0	95.0
Kale............	Slowly in freezer.	July 3,'13	-3.5	5	80.0	95.0
Cabbage..........	Rapidly in room.	May 15,'13	-5	4	100.0	100.0
Cabbage..........	Slowly in freezer.	May 15,'13	-5	4	100.0	100.0
Red Cabbage.....	Rapidly in room.	May 15,'13	-5	5	20.0	20.0
Red Cabbage.....	Slowly in freezer	May 15,'13	-5	9	33.3	33.3
Cabbage, Flat Dutch.....	Rapidly in room.	June 12,'13	-4	20	100.0	100.0
Cabbage, Flat Dutch.....	Slowly in room..	June 12,'13	-4	10	100.0	100.0
Cabbage..........	Rapidly in room.	June 28,'13	-3.5	5	40.0	85.0
Cabbage..........	Slowly in freezer.	June 28,'13	-3.5	5	40.0	85.0
Cabbage..........	Rapidly, fanned.	June 28,'13	-3.5	5	40.0	85.0

Material	Manner of Thawing	Date	Temperature	Number of Leaves	Percentage all Killed	Percentage Total Surface Killed
Cabbage, Red Rock......	Rapidly in room.	June 30,'13	-4	5	40.0	65.0
Cabbage, Red Rock......	Slowly in freezer.	June 30,'13	-4	5	60.0	65.0
Cabbage, Red Rock......	Rapidly, fanned.	June 30,'13	-4	5	60.0	70.0
Tomatoes.........	Rapidly in room.	June 28,'13	-3.5	26	100.0	100.0
Tomatoes.........	Slowly in freezer.	June 28,'13	-3.5	25	100.0	100.0
Tomatoes.........	Rapidly, fanned.	June 28,'13	-3.5	25	100.0	100.0
Elberta peach leaves....	Rapidly........	July 16,'13	-6	9	44.4	58.9
Elberta peach leaves....	Slowly..........	July 16,'13	-6	8	0.0	25.0
Elberta peach leaves....	Rapidly........	July 17,'13	-5	57	0.0	17.9
Elberta peach leaves....	Slowly..........	July 17,'13	-5	58	0.0	18.9
Late Duchess apple leaves.....	Rapidly........	July 16,'13	-6	22	0.0	28.4
Late Duchess apple leaves.....	Slowly..........	July 16,'13	-6	19	0.0	19.7
Late Duchess apple leaves.....	Rapidly........	July 17,'13	-5	51	0.0	27.4
Late Duchess apple leaves.....	Slowly	July 17,'13	-5	55	0.0	26.3
Average, Leaves of succulent plants, thawed slowly..................						68.4
Average, Leaves of succulent plants, thawed rapidly..................						76.3
Average, Same, excluding lettuce, thawed slowly......................						74.4
Average, Same, excluding lettuce, thawed rapidly......................						76.2

In none of these plants, except lettuce, does there seem to be any difference in the amount of killing on account of the rate of thawing. Lettuce, however, seems to have the amount of injury reduced by slow thawing. Even with lettuce, however, a slight reduction in temperature, certainly not more than one degree, would offset the effect of slow thawing.

Effect of Wilted Condition on Killing Temperature. The condition of plant tissue at the time of freezing with reference to turgidity seems to have something to do with the killing. In all freezings care has been taken to have all of the plants kept in an equally turgid condition, or as nearly so as it was possible to maintain, though to find to what extent slight difference in turgidity might alter results, a considerable number of plants were frozen, some turgid and some wilted. The following table gives a list of freezings and the results:

TABLE 18. SHOWING EFFECT OF WILTING OF PLANT TISSUE ON ITS RESISTANCE TO COLD (FRUITS).

Material	Date	Temperature	Number of Fruits	Percentage Killed	Percentage Weight Lost
PEACHES					
Elberta Seedling, turgid.......	May 24,'13	-4	21	61.9	
Elberta Seedling, wilted on twig......................	May 24,'13	-4	29	17.2	
Elberta Seedling, wilted 3½ hrs. detached..............	May 24,'13	-4	29	24.2	27.6
Lewis, fresh.................	May 19,'13	-4	23	43.5	
Lewis, wilted 6 hrs. on twig...	May 19,'13	-4	22	45.5	
Early Bernard, turgid........	May 21,'13	-4	34	61.8	
Early Bernard, wilted 5 hrs. on twig..................	May 21,'13	-4	53	69.8	4.0
APPLES					
Jonathan, turgid............	May 24,'13	-4	23	56.5	
Jonathan, wilted on twig......	May 24,'13	-4	29	83.8	2.0
Jonathan, wilted detached....	May 24,'13	-4	26	65.4	
Jonathan, turgid............	May 19,'13	-4	19	68.4	
Jonathan, wilted on twig 6 hrs.	May 19,'13	-4	37	86.5	
Salome, turgid..............	June 12,'13	-4.5	15	46.7	
Salome, wilted on twig........	June 12,'13	-4.5	12	50.0	
CHERRIES					
Dyehouse, turgid............	May 21,'13	-4	38	39.5	
Dyehouse, wilted 5 hrs. on twig.....................	May 21,'13	-4	56	21.4	3.4
Average percentage of fruits killed, fresh.................				54.0	
Average percentage of fruits killed, wilted on twig.........				53.5	

TABLE 18a. SHOWING EFFECT OF WILTING OF PLANT TISSUE ON ITS RESISTANCE TO COLD. (SUCCULENT PLANTS.)

Material	Date	Temperature	Number of Leaves	Percentage all Killed	Percentage Total Surface Killed	Percentage Weight Lost
Tomato, turgid	Aug. 10,'12	-3	2		80.0	
Tomato, wet and turgid	Aug. 10,'12	-3	2		90.0	
Tomato, wilted	Aug. 10,'12	-3	2		85.0	
Tomato, turgid	Aug 11,'12	-2	2		20.0	
Tomato, wet and turgid	Aug. 11,'12	-2	2		40.0	
Tomato, wilted	Aug. 11,'12	-2	2		30	
Tomato, turgid	June 25,'13	-2.5	32	50.0	72.6	
Tomato, wet and turgid	June 25,'13	-2.5	32	69.2	88.4	
Tomato, wilted	June 25,'13	-2.5	37	43.2	62.8	15.6
Tomato, turgid	June 30,'13	-2.5	35	....	97.5	
Tomato, wilted	June 30,'13	-2.5	24	....	58.0	28.0
Kale, turgid	July 3,'13	-3.5	5	80.0	95.0	
Kale, wilted	July 3,'13	-3.5	5	60.0	85.0	35.4
Red Rock Cabbage, turgid	June 30,'13	-4	5		65.0	
Red Rock Cabbage, wilted	June 30,'13	-4	4		43.9	16.8
Lima bean, turgid	June 22,'12	-2	5		15.0	
Lima bean, wilted	June 22,'12	-2	5		75.0	
Lettuce, turgid	July 25,'12	-2	5		0.0	
Lettuce, wet and turgid	July 25,'12	-2	5		50.0	
Lettuce, wilted	July 25,'12	-2	5		0.0	
Lettuce, turgid	July 27,'12	-2	5		0.0	
Lettuce, wet and turgid	July 27,'12	-2	5		30.0	
Lettuce, wilted	July 27,'12	-2	5		60.0	
Lettuce, turgid	July 30,'12	-2	5		25.0	
Lettuce, wet and turgid	July 30,'12	-2	5		25.0	
Lettuce, wilted	July 30,'12	-2	5		35.0	
Black Seeded Simpson lettuce, turgid	June 12,'13	-4	9	92.5	66.6	
Black Seeded Simpson lettuce, wilted	June 12,'13	-4	9	33.3	55.5	23.4
Black Seeded Simpson lettuce, turgid	June 13,'13	-4.5	12	75.0	83.0	
Black Seeded Simpson lettuce, wilted	June 13,'13	-4.5	14	57.0	62.0	21.8
Turnip, turgid	July 25,'12	-2	4		0.0	
Turnip, wet and turgid	July 25,'12	-2	4	....	30.0	....
Turnip, wilted	July 25,'12	-2	4	....	30.0	....
Turnip, turgid	July 27,'12	-2	4	....	40.0	....
Turnip, wet and turgid	July 27,'12	-2	4	....	10.0	....
Turnip, wilted	July 27,'12	-2	4	....	10.0	....
Red Clover, turgid	July 22,'12	-2	4	....	17.0	....
Red Clover, wilted	July 22,'12	-2	4	....	34.0	....
Red Clover, turgid	July 24,'12	-3	4	....	100.0	....
Red Clover, wilted	July 24,'12	-3	4	....	66.0	....
Rose Geranium, turgid	July 22,'12	-2	4	....	97.0	....
Rose Geranium, wilted	July 22,'12	-2	4	....	60.0	....
Rose Geranium, turgid	July 24,'12	-3	4	....	100.0	....

Material	Date	Temperature	Number of Leaves	Percentage all Killed	Percentage Total Surface Killed	Percentage Weight Lost
Rose Geranium, wet and turgid..........	July 24,'12	-3	4	....	100.0	....
Rose Geranium, wilted.	July 24,'12	-3	4	....	100.0	....
Common Geranium, turgid..............	July 24,'12	-3	4	....	95.0	....
Common Geranium, wet and turgid......	July 24,'12	-3	4	....	90.0	....
Common Geranium, wilted.............	July 24,'12	-3	4	....	100.0	....
Common Geranium, turgid..............	July 31,'12	-2	4	....	100.0	....
Common Geranium, wet and turgid......	July 31,'12	-2	4	....	80.0	....
Common Geranium, wilted.............	July 31,'12	-2	4	....	100.0	....
Morning-glory, turgid..	July 31,'12	-2	3	....	100.0	....
Morning-glory, wet and turgid..........	July 31,'12	-2	3	....	100.0	....
Morning-glory, wilted..	July 31,'12	-2	3	....	0.0	....
Morning-glory, turgid..	Aug. 3,'12	-2	4	....	15.0	....
Morning-glory, wet and turgid..........	Aug. 3,'12	-2	4	....	100.0	....
Morning-glory, wilted..	Aug. 3,'12	-2	4	....	15.0	....
Coleus, turgid.........	Sept. 3,'12	-2.5	4	....	25.0	....
Coleus, wet and turgid	Sept. 3,'12	-2.5	4	....	50.0	....
Coleus, wilted.........	Sept. 3,'12	-2.5	4	....	100.0	....
Fern, turgid..........	Sept. 6,'12	-2	5	....	0.0	....
Fern, wet and turgid...	Sept. 6,'12	-2	5	....	15.0	....
Fern, wilted..........	Sept. 6,'12	-2	5	....	60.0	....
Fern, turgid..........	Sept. 7,'12	-2	5	....	5.0	....
Fern, wet and turgid...	Sept. 7,'12	-2	5	....	7.0	....
Fern, wilted..........	Sept. 7,'12	-2	5	....	20.0	....
Fern, turgid..........	Sept. 9,'12	-2	5	....	40.0	....
Fern, wet and turgid...	Sept. 9,'12	-2	5	....	55.0	....
Fern, wilted..........	Sept. 9,'12	-2	5	....	40.0	....
Mulberry, turgid......	Sept. 9,'12	-2	5	....	5.0	....
Mulberry, wet and turgid..............	Sept. 9,'12	-2	5	....	0.0	....
Mulberry, wilted......	Sept. 9,'12	-2	5	....	0.0	....
Average percentage surface killed, leaves of succulent plants, turgid....................................					50.3	
Average percentage surface killed, leaves of succulent plants, wilted....................................					51.4	

On January 22, 1913, apple roots from one-year-old seedling stock were frozen to -9° C in 3¼ hours:

(a) Two kept in water 18 hours.

All were injured. The crown cuts slightly in cambium; and the second and third in cambium and cortex severely.

(b) Two roots kept in saw dust.

The crown cuts were very slightly injured; the second and third were more severely than the crown cuts, but less severely than the second and third cuts of (a).

(c) Two dried roots—allowed to dry on desk eighteen hours.

Crown cuts and second cuts entirely uninjured. Very slight injury in cambium region of third cut.

There is some indication that rapid wilting in case of some plants reduces the injury from freezing. However, in the case of most plants the difference is rather slight and with many plants there is no apparent difference. In all cases the wilting was sufficient to give the tissue a limp appearance. It seems rather certain then that wilting so slight that it can not be easily detected by the appearance or feel of the tissue could not influence the results in freezing such tissue as our plants with roots or stem bases in solutions. In case of plants with the surface wet, listed in the table as wet and turgid, there seems strong evidence that the killing from freezing is worse.

Long continued partial withholding of water is different. The rate of growth, sap density and possibly the resistance of the protoplasm to the results of low temperature are increased. There is no apparent reason to expect this of rapid wilting. It would temporarily increase the sap density by reducing the amount of water in the cell. It probably does not, however, increase the amount of material in the cell to hold water. Plants growing with insufficient water supply are generally more resistant to cold (See tables IV, V, and VI). We have also some results of this effect of continued partial withholding of water on dormant peach buds. On November 20, 1910, typical branches of peach trees were girdled, a ring being cut nearly through the sap wood, and another limb was cut off and set up in the tree. This was done with several trees. The following table gives the percentage of buds killed when the temperature went to -8° F., on January 3, 1911:

TABLE 19. SHOWING EFFECT OF SLOW DRYING OUT ON HARDINESS OF PEACH BUDS IN WINTER.

Variety	Buds From	Date	Number of Buds	Percentage Killed
Barnes......	Girdled branch................	Jan. 14,'11	321	19.3
Barnes......	Cut off branch.................	Jan. 14,'11	275	29.5
Barnes......	Check, normal branch..........	Jan. 14,'11	325	86.0
Connolly....	Girdled branch................	Jan. 14,'11	198	68.7
Connolly....	Cut off branch.................	Jan. 14,'11	281	68.0
Connolly....	Check, normal branch..........	Jan. 14,'11	217	89.9
Hills Chili...	Girdled branch................	Jan. 14,'11	501	11.4
Hills Chili...	Cut off branch.................	Jan. 14,'11	351	18.0
Hills Chili...	Check, normal branch..........	Jan. 14,'11	465	45.2
Average, Girdled branch..				33.1
Average, Cut off branch..				38.5
Average, Check, normal branch................................				73.7

It is plain that this slow loss of water in case of winter resting fruit buds has increased the resistance of the tissue to low temperature.

Rate of Freezing. Pfeffer[1] makes the following statement with reference to the rate of freezing: "Resistant plants withstand rapid and slow cooling equally well, and it is doubtful whether a rapid fall of temperature is more injurious to plants killed by freezing than is gradual cooling. That the injury is not due to the sudden formation of ice after sub-cooling is shown by the fact that a peeled potato is killed by freezing, although no sub-cooling occurs and the ice forms gradually at -1° C., the freezing point of the sap." However, lately Winkler[2], working with Pfeffer, finds that with winter twigs that on cooling rapidly to -22° C. will be killed, if they are kept for three days at -16° C., two days at -18° C., three days at -20° C., two days at -22° C., three days at -25° C., and twelve hours at -30° to -32° C., they were not all killed.

The rate of temperature fall is very important indeed, especially in case of winter buds. In fact apple buds can be frozen in a chamber surrounded by salt and ice rapidly enough that practically all of them will be killed at a temperature of zero F., or slightly below, while it is well known that they may go through a temperature of

[1]Phys. of Plants. Eng. Trans. by Ewart, Vol. 2, p. 235. (Bibl. No. 88).
[2]Jahrb. f. Wiss. Bot. Vol. 52, 1913, pp. 467-506. (Bibl. No. 121).

20° F. to 30° F. below zero with but slight injury where the temperature fall is not so rapid. No fruit buds have been found on the Experiment Station grounds that can not be killed by a temperature secured by salt and ice when in the most dormant state, by very rapid fall. The following is a list of the freezings in our laboratory, with the results:

TABLE 20. SHOWING EFFECT OF SLOW AND RAPID TEMPERATURE FALL ON FREEZING TO DEATH OF PLANT TISSUE.

Kind of Buds	Date	Number Buds	Percentage Killed	Number Buds	Percentage Killed
		Slowly to -19.5° C.		Rapidly to -17.7° C.	
Rice's Seedling peach	Jan. 25,'13	80	15	55	96.4
Yellow Swan peach	Jan. 25,'13	64	28	86	100.0
Early Richmond cherry	Jan. 25,'13	100	16	90	97.7
		Slowly to -20° C.		Rapidly to -19° C.	
Rice's Seedling peach	Feb. 15,'13	117	10.3	68	100.0
Yellow Swan peach	Feb. 15,'13	95	30.5	64	100.0
Early Richmond cherry	Feb. 15,'13	100	45.0	89	98.8
Dyehouse cherry	Feb. 15,'13	83	22.9	90	97.6
		Slowly to -18.5° C.		Rapidly to -12° C.	
Rice's Seedling peach	Mar. 15,'13	104	42.3	101	37.6
Elberta peach	Mar. 15,'13	104	97.7	86	61.6
Jonathan apple	Mar. 15,'13	35	34.3	20	70.0
Montmorency cherry	Mar. 15,'13	85	14.1	87	17.2
Lombard plum	Mar. 15,'13	112	12.9	99	47.3
		Slowly to -15.5° C.		Rapidly to -10° C.	
Hills Chili peach	Feb. 22,'13	63	17.3	49	10.2
Rice's Seedling peach	Feb. 22,'13	104	10.6	81	4.9
Early Richmond cherry	Feb. 22,'13	94	29.8	73	54.8
		Slowly to -18° C.		Rapidly to -13.5° C.	
Elberta peach	Mar. 8,'13	66	30.3	92	70.6
Hills Chili peach	Mar. 8,'13	120	20.8	71	76.0
Rice's Seedling peach	Mar. 8,'13	70	21.4	82	54.9
		Slowly to -18° C.		Rapidly to -13.5° C.	
Rice's Seedling peach	Mar. 22,'13	138	44.2	154	51.9
Elberta peach	Mar. 22,'13	100	88.0	85	92.9
Jonathan apple	Mar. 22,'13	34	64.7	33	75.7
Montmorency cherry	Mar. 22,'13	176	58.5	184	62.5
Chabot plum	Mar. 22,'13	236	78.3	183	86.8

Kind of Buds	Date	Number Buds	Percentage Killed	Number Buds	Percentage Killed
		Slowly to -16.5° C.		Rapidly to -11.5° C.	
Rice's Seedling peach.......	Mar. 24,'13	145	57.0	158	53.2
Elberta peach.............	Mar. 24,'13	170	82.9	86	75.5
Jonathan apple............	Mar. 24,'13	39	46.2	40	70.0
Montmorency cherry.......	Mar. 24,'13	166	76.5	189	59.2
Chabot plum..............	Mar. 24,'13	191	100.0	176	73.8
		Slowly to -16° C.		Rapidly to -12.5° C.	
Elberta peach.............	Nov. 3,'10	382	77.8	188	69.1
		Slowly to -16.5° C.		Rapidly to -16° C.	
Elberta peach.............	Dec. 7,'11	150	1.3	200	100.0
		Slowly to -16.2° C.		Rapidly to -16.5° C.	
Elberta peach.............	Dec. 7,'11	210	14.8	150	96.6

TABLE 20a. SHOWING EFFECT OF SLOW AND RAPID TEMPERATURE FALL ON FREEZING TO DEATH OF PLANT TISSUE.

Kind of Buds	Manner of Freezing	Date	Number Buds	Percentage Killed
Montmorency cherry.......	Slowly to -20° C..	Mar. 2,'12	163	3.0
Montmorency cherry.......	Rapidly to -20° C.	Feb. 29,'12	130	96.0
Early Richmond cherry.....	Slowly to -20° C..	Mar. 9,'12	297	5.0
Early Richmond cherry.....	Rapidly to -20° C.	Mar. 14,'12	263	98.0

TABLE 20b. SHOWING EFFECT OF SLOW AND RAPID TEMPERATURE FALL ON FREEZING TO DEATH OF PLANT TISSUE.

Kind of Buds	Date	Temperature	Time	Number Buds	Percentage Killed
Ben Davis apple............	Jan. 18,'12	-20.5	2 hrs.....	40	50.0
Ben Davis apple............	Jan. 19,'12	-20.5	2 hrs.....	47	36.2
Ben Davis apple............	Feb. 2,'12	-20	1½ hrs...	60	0.0
Ben Davis apple............	Feb. 3,'12	-20	2½ hrs...	82	2.44
Jonathan apple.............	Jan. 18,'12	-20.5	2 hrs.....	35	48.6
Early Richmond cherry.......	Jan. 18,'12	-21	1½ hrs...	272	98.6
Early Richmond cherry.......	Jan. 19,'12	-20.5	2 hrs.....	200	100.0
Montmorency cherry.........	Jan. 19,'12	-20.5	1¼ hrs...	178	87.0
Early Richmond cherry.......	Feb. 9,'12	-20.5	1½ hrs...	252	100.0
Montmorency cherry.........	Feb. 10,'12	-20.5	1¼ hrs...	195	94.8
Cherry.....................	Feb. 15,'12	-20.5	12 hrs.... (slowly)	132	38.0
Rapidly, +20° C. to -17° C. in 45 minutes					
Jonathan apple.............	Feb. 20,'13			20	100.0
Vermont Beauty pear........	Feb. 20,'13			25	100.0
Chabot plum................	Feb. 20,'13			28	100.0

Table 20c. Showing Effect of Slow and Rapid Temperature Fall on Freezing to Death of Plant Tissue.

Material	Date	Time	Temperature	Results
Elberta peach twigs	Mar. 21,'13	7¼ hrs.	−18	Sap wood and pith only injured regions. Rice's Seedling showed the least injury. Others injured equally. Killing about the same for twigs whose temperature fell rapidly to −13.5° and those whose temperature fell slowly to −18°. (Buds injured worst in rapidly frozen ones).
Rice's Seedling peach twigs	Mar. 21,'13	7¼ hrs.	−18	
Jonathan apple twigs	Mar. 21,'13	7¼ hrs.	−18	
Chabot plum twigs	Mar. 21,'13	7¼ hrs.	−18	
Montmorency cherry twigs	Mar. 21,'13	7¼ hrs.	−18	
Elberta peach twigs	Mar. 21,'13	1¾ hrs.	−13.5	
Rice's Seedling peach twigs	Mar. 21,'13	1¾ hrs.	−13.5	
Jonathan apple twigs	Mar. 21,'13	1¾ hrs.	−13.5	
Chabot plum twigs	Mar. 21,'13	1¾ hrs.	−13.5	
Montmorency cherry twigs	Mar. 21,'13	1¾ hrs.	−13.5	
Elberta peach twigs	Mar. 22,'13	1 hr.	−11.5	Pith and sap wood injured.
Elberta peach twigs	Mar. 22,'13	7½ hrs.	−16.5	Pith and sap wood injured. Very slight browning in cortex; none in cambium.
Rice's Seedling peach twigs	Mar. 22,'13	1 hr.	−11.5	No difference in injury between rapid and slow. Pith and sap wood slightly injured in both.
Rice's Seedling peach twigs	Mar. 22,'13	7½ hrs.	−16.5	
Jonathan apple twigs	Mar. 22,'13	1 hr.	−11.5	Pith injured in both cases. No other tissues injured.
Jonathan apple twigs	Mar. 22,'13	7½ hrs.	−16.5	
Montmorency cherry twigs	Mar. 22,'13	1 hr.	−11.5	Pith injured in both cases.
Montmorency cherry twigs	Mar. 22,'13	7½ hrs.	−16.5	
Chabot plum twigs	Mar. 22,'13	1 hr.	−11.5	Pith and sap wood injured equally in both cases.
Chabot plum twigs	Mar. 22,'13	7½ hrs.	−16.5	

With these twigs it will be seen that the killing temperature of rapidly frozen twigs was four and a half degrees higher than that of the more slowly frozen twigs, and even then the buds of the rapidly frozen twigs killed the worst.

In rapid freezing it required from one to one and three-fourths hours to reach a temperature of -20° C. In slow freezing it required from seven to ten hours to reach the same temperature. Many young fruits and succulent plants were also frozen slowly and rapidly

but there was so little apparent difference between the results that the data are not given. The killing temperature lies so near the freezing point that possibly the slowly frozen tissue kills badly because it is exposed to temperatures around the killing point longer. This tender tissue was exposed to the minimum temperature for from twenty to thirty minutes.

It will be seen that the rate of temperature fall with winter twigs and buds exerts the greatest influence on the extent of killing at a given temperature of any feature we have so far discussed. And in the case of very forward, rather tender fruit buds, the rate of temperature fall exerts great influence. Thus on March 24, 1913, when all buds, especially of peaches, plums and cherries, had made much growth, a temperature of -11.5° C. killed as many buds with rapid temperature fall as a temperature of -16.5° C. with a slower temperature fall.

Tests were made to see whether the rapid temperature fall that does the most harm is in the early part of the ice forming state, or in the later part. The following table gives the results with peach buds frozen slowly one-half way down to the killling temperature and rapidly the remainder of the way, and others frozen rapidly one-half the way down and slowly the remainder of the way, and others slowly all the way down:

TABLE 21. SHOWING THE RELATIVE EFFECT ON THE RESISTANCE TO LOW TEMPERATURE OF RAPID TEMPERATURE FALL TOWARD THE BEGINNING AND TOWARD THE END OF THE FREEZING PERIOD.

Kind of Buds	Manner of Freezing	Date	Number of Buds	Percentage Killed
Elberta peach	Slow to –12; fast –12 to –16	Dec. 20,'11	135	3.7
Elberta peach	Fast to –12; slow –12 to –16	Dec. 20,'11	77	71.4
Elberta peach	Slow to –17.5	Dec. 20,'11	129	6.2
Elberta peach	Fast to –16	Dec. 8,'13	135	98.5
Elberta peach	Slow to –12; fast to –16	Dec. 8,'11	113	3.5
Elberta peach	Fast to –12; slow to –16	Dec. 8,'11	135	29.0
Elberta	Medium to –12; fast to –16	Dec. 13,'11	155	52.3
Montmorency cherry	Fast to –12; slow to –20	Feb. 24,'12	142	75.0
Montmorency cherry	Slow to –12; fast to –20	Feb. 27,'12	136	15.4
Montmorency cherry	Fast to –20	Feb. 27,'12	130	96.0
Montmorency cherry	Slow to –20	Mar. 2,'12	163	3.0
Early Richmond cherry	Slow to –12; fast to –20	Mar. 5,'12	291	14.0
Early Richmond cherry	Fast to –12; slow to –20	Mar. 7,'12	283	83.0
Early Richmond cherry	Slow to –20	Mar. 9,'12	297	5.0
Early Richmond cherry	Fast to –20	Mar. 14,'12	263	98.0
Dyehouse cherry	Slow to –12; fast to –20	Mar. 16,'12	184	56.0
Dyehouse cherry	Fast to –12; slow to –20	Mar. 19,'12	200	99.0
Dyehouse cherry	Fast to –20	Mar. 22,'12	150	95.0

It will be seen that rapid falling in the early part of the freezing period down to -12° C., does more harm than rapid fall in the latter part of the period, from -12° C. to the killing temperature. This rapid freezing probably has considerable to do with the amount of killing at times in nature, though just how much it is difficult to tell. In this investigation it was not possible to cause, the temperature to fall more slowly than the most rapid fall to be observed naturally in the climate of this station. Yet there are probably times when on sunny, cold days the temperature of some tissue may rise to near the freezing point due to the absorption of the heat by the dark color of the bark. In this case when the sun is off the twigs, the tempera-

ture will fall very rapidly. Since rapid temperature fall near the freezing point seems to be more harmful than rapid temperature fall near the killing temperature, it would seem certain that greater killing should thus result. It does not seem impossible that "sun scald" of apple trees may be explained in this way.

This rapid fall of temperature may also be a feature to be considered in heating an orchard. Thus any one who has worked with orchard heaters knows that if on a still night a few of the heaters go out, the temperature will immediately fall to about that which would prevail without the heaters. In this case it is possible that the tissue may kill worse than if the heaters had not been there, since the blossoms or fruit would freeze very rapidly. We can not be certain of this, however, for results with rapid freezing of blossoms at this station have not been uniform enough to be conclusive.

Maturity and Hardiness. Probably the greatest factor in determining the amount of cold that can be withstood by trees and shrubs that live through the winter is a condition of maturity. Emerson[1] has studied the question of maturity of fruit and other trees in Nebraska and has found that the varieties most hardy in wood are those that mature early. Where growth can be checked early in the season, as by a gross feeding cover crop like millet, the trees will also withstand more cold.

Selby[2] made a study of the injury to fruit trees and ornamentals by the severe freeze early in the winter of 1903-4, and attributes the severe injury to the fact that the trees grew late in the fall on account of a very wet period following a period of dry weather.

Eustace[3] reports a study of the effect of the same winter on fruit trees and describes similar conditions. It seems in this case also the great injury is due to the trees' having grown late in autumn.

Winkler[4] found that the resistance of native trees of Germany is least in May, June, July, and August, and gradually increases during September, October, November and December, and is greatest in January, as measured by laboratory freezings.

In summer the fruit buds, for example in August after they can be easily detected, may be killed by a temperature of -9° to -10° C. or somewhat lower on some years. At this time there is little difference between the hardiness of the buds, the wood, and even the foliage, though the foliage kills slightly the worst; while in winter fruit

[1]Nebraska Agr. Exp. Sta. Bul. 79, 1903, (Bibl. No. 33); Neb. Agr. Exp. Sta. Bul. 92, 1906, (Bibl. No. 34); Neb. Agr. Exp. Sta. Anl. Rpt. No. 19, 1906, pp. 101-10, (Bibl. No. 35).
[2]Ohio Agr. Exp. Sta. Bul. 192, 1908. (Bibl. No. 101).
[3]New York (Geneva) Agr. Exp. Sta. Bul. 269, 1905. (Bibl. No. 38).
[4]Jahrb. f. Wiss. Bot. Vol. 52, 1913, pp. 467-506. (Bibl. No. 121).

buds have been known to survive temperatures of -30° C. and lower, and the tree will survive, under favorable conditions, considerably lower temperature than that. In fact Macoun[1] cites an instance where a Pyrus baccata—Pyrus Malus hybrid—has withstood for five years a climate whose temperature frequently falls to -50° F., and in 1909 it fell twice to -59° F.

At the beginning of winter, as observed by the authors above, the tree tissue generally—whether it is buds, wood, cambium or cortex—will stand less cold than later in the winter. Observation at this station indicates that at least some tissue increases in hardiness rather rapidly for a short time following leaf fall. The following table gives the temperature and result of freezing peach fruit buds, beginning in summer when they are first plainly to be observed and continuing until January:

TABLE 22. SHOWING THE RELATIVE HARDINESS OF FRUIT BUDS AT VARIOUS SEASONS OF THE YEAR.

Kind of Buds	Date	Temperature	Number of Buds	Percentage Killed
Elberta peach buds	July 15,'13	- 6	23	78.2
Elberta peach buds	July 16,'13	- 5	47	100.0
Elberta peach buds	Sept. 15,'11	- 9	186	64.6
Elberta peach buds	Sept. 27,'10	-15	245	39.0
Elberta peach buds	Nov. 1,'10	-16	382	77.8
Elberta peach buds	Nov. 1,'11	- 9	104	60.5
Elberta peach buds	Nov. 14,'11	-12.5	188	69.1
Elberta peach buds	Nov. 12,'09	-13.5	198	1.5
Elberta peach buds	Nov. 17,'11	-14.5	133	100.0
Elberta peach buds	Nov. 18,'11	-12.3	100	91.0
Elberta peach buds	Nov. 18,'11	-13.3	150	99.3
Elberta peach buds	Dec. 1,'09	-22	385	75.3
Elberta peach buds	Dec. 1,'09	-21	343	84.2
Elberta peach buds	Dec. 6,'11	-14.7	225	40.0
Elberta peach buds	Dec. 6,'11	-16	278	56.5
Elberta peach buds	Dec. 14,'09	-20.5	190	74.7
Elberta peach buds	Dec. 18,'09	-22	608	48.2
Elberta peach buds	Jan. 8,'13	-20	105	51.0
Elberta peach buds	Jan. 13,'10	-20	290	97.0
Elberta peach buds	Feb. 23,'10	-19.5	168	63.1
Oldmixon peach buds	Aug. 23,'10	- 8.5	162	93.2
Oldmixon peach buds	Nov. 26,'09	-18	160	81.2
Oldmixon peach buds	Nov. 26,'09	-19.5	229	15.3
Oldmixon peach buds	Dec. 6,'09	-22	290	93.1
Late Duchess apple buds	July 15,'13	- 6	20	70.0
Jonathan apple buds	July 15,'13	- 5	53	73.6
Jonathan apple buds	Nov. 4,'11	-12.5	68	48.5
Jonathan apple buds	Jan. 18,'12	-20.5	35	58.6

[1] Procs. Soc. for Hort. Science, 1912, p. 65. (Bibl. No. 69).

The following table gives the result of freezing twigs:

TABLE 23. SHOWING KILLING TEMPERATURE OF TWIG TISSUE AT DIFFERENT SEASONS.

Variety	Date	Temperature	Results
PEACHES			
Elberta	July 6,'13	− 6	13 twigs. Cambium dead in 5; cambium and cortex in 8.
Elberta	July 17,'13	− 5	20 twigs. Cambium and cortex dead in all.
Young Champion	July 29,'12	− 5	Twigs 10" long. All tissue injured in terminal 6"; slight injury to cortex only at base of tree.
Champion	Aug. 5,'12	− 5	Bark and cambium killed in all stems.
Belle of Georgia five years old	Aug. 29,'12	− 5	Bark, cambium and sap wood killed in all twigs.
Elberta	Sept. 24,'12	− 5	Bark, cambium, and outer portion sap wood killed.
Elberta, one year old	Oct. 5,'12	− 5	Cambium and cortex injured except at base of one twig. Only injury to sap wood was in terminal part of one twig.
Seedling peach, one year old	Oct. 8,'12	− 5	Twigs injured in cambium and cortex region.
Elberta	Oct. 14,'11	− 9.5	24 twigs. 100% dead. Cambium only killed.
Elberta	Oct. 19,'11	− 5	38 twigs. No injury.
Elberta	Oct. 21,'11	− 7.5	46 twigs. 73.9% dead. Cambium only killed.
Elberta	Oct. 26,'11	− 9	39 twigs. Killing confined largely to cambium.
Elberta	Nov. 1,'11	− 9	23 twigs. 60.6% killed. Cambium only injured.
Elberta	Nov. 2,'11	− 9	51 twigs. 84.3% killed. Cambium only injured.
Elberta	Nov. 16,'12	−15	Slight injury in cortex. Cambium uninjured.
Elberta	Dec. 6,'12	−15	Cortex injured in all; cambium uninjured; pith killed and sap wood occasionally showed injury.
Seedling, one year old	Dec. 18,'12	−16.5	Injured slightly in cortex and pith; cambium and wood sap uninjured.
Seedling, one year old	Dec. 19,'12	−18	Injury confined to pith and cortex.
Elberta	Dec. 7,'12	−16	Injury confined to shoulder below bud and pith region.
Elberta	Jan. 11,'13	−20	Pith dead, other tissues uninjured.
Rice's Seedling	Jan. 25,'12	−19.3	Cortex injured slightly; cambium entirely killed.
Elberta	Mar. 21,'13	−18	Injury to sap wood and pith.
Rice's Seedling	Mar. 21,'13	−18	Injury to sap wood and pith less than with Elberta.
Elberta	Apr. 5,'13	−12.5	Wood uninjured.

Variety	Date	Temperature	Results
APPLE TWIGS			
Jonathan twigs.......	May 17,'13	− 4	Cortex and epidermis hardiest in a given part. Near base twigs hardier than near tip.
Jonathan twigs.......	May 24,'13	− 4	Slight injury near terminal part.
Jonathan twigs.......	June 7,'13	− 5	Cambium injured throughout all twigs. In terminal 3 in. injury extended to cortex, sap wood and pith. Terminal leaflets more severely injured than remaining ones.
Ben Davis, seven years old.....	June 26,'13	− 4	Severe injury in cambium, cortex and sap wood.
Young Early Harvest.	June 27,'13	− 4	Very slight injury in cambium near terminal.
Early Harvest........	June 27,'13	− 5	Cambium, cortex, sap wood and pith injured. More severe near terminal.
Ben Davis, five years old.......	July 2,'13	− 4.5	Cambium and cortex severely injured. Sap wood injured.
Late Duchess.........	July 15,'13	− 6	4 twigs; no injury.
Jonathan twigs.......	July 16,'13	− 5	20 twigs; no injury.
Young apple.........	July 27,'12	− 5	All tissue injured 4" back from terminal. No tissue injured farther back than 7" from terminal. Cortex injured most and cambium next.
Jonathan............	Aug. 15,'12	− 5	Cortex and cambium injured slightly in all samples. Sap wood and pith not injured. Only slight difference between younger and older parts.
Ben Davis...........	Oct. 9,'12	− 8	No parts killed.
Ben Davis...........	Oct. 13,'12	− 9.5	No parts killed.
Jonathan............	Oct. 16,'12	−15	Cortex killed; cambium uninjured.
Jonathan............	Nov. 4,'11	−12.5	23 twigs. No injury.
Jonathan, one year old........	Nov. 16,'11	−15	Slightly injured in cortex. Cambium uninjured.
Jonathan, one year old........	Nov. 27,'11	−20	38.5 inches of twigs; 67.5% killed in all tissues.
Ben Davis, one year old........	Nov. 27,'11	−20	40.5 inches of twigs; 14.8% killed in all tissues.
Jonathan, one year old........	Nov. 29,'11	−19.4	158 inches of twigs; 34.1% killed in all tissues.
Ben Davis, one year old........	Nov. 29,'11	−19.4	No injury.
Ben Davis, one year old........	Nov. 29,'11	−21	80 inches of twigs; 7.5% killed in all tissues.
Gano, two years old.......	Nov. 29,'11	−21	38 inches of twigs; 7.8% killed in all tissues.
Jonathan, one year old........	Dec. 5,'11	−20	136 inches of twigs; 59.8% killed in all tissues.
Gano, two years old.......	Dec. 11,'11	−20.7	113 inches of twigs; 15% killed in all tissues.

Variety	Date	Temperature	Results
PLUM TWIGS			
Mature plum tree....	July 30,'12	- 5	Cambium, pith and cortex injured throughout. Sap wood slightly injured throughout.
Marianna............	Oct. 9,'12	- 8	Very slight injury.
Marianna, one year old........	Nov. 8,'11	-11	New shoots all killed only in spots at basal ends.
Marianna, one year old........	Dec. 18,'12	-16.5	Injury in cortex and pith. Sap wood and cambium uninjured.
Marianna, one year old........	Dec. 19,'12	-18	Injury confined to pith and cortex, slight injury to pith. Other tissues uninjured.
Marianna............	Jan. 11,'13	-20	Slight injury to pith. Other tissues uninjured.

Eustace[1] often observed the greatest injury to peach trees to be just above the snow line. Following the winter of 1904 Green and Ballou[2] reported that an Ohio fruit grower was able to save his trees by banking the bodies with manure, thus keeping the temperature of the trunks near the ground from going as low as that to which the remainder of the tree was exposed.

To test this point at the Missouri Experiment Station, sections of tissue from young and old trees were taken at different points along the trunk beginning near the ground and continuing upward into the branches. These were collected and frozen at intervals throughout the year beginning in September and ending the following July. The results are shown in the following tables:

[1]New York (Geneva) Agr. Exp. Sta. Bul. 269, 1905. (Bibl. No. 38).
[2]Ohio Agr. Exp. Sta. Bul. 157, 1894. (Bibl. No. 48).

TABLE 24. SHOWING RELATIVE HARDINESS OF DIFFERENT TISSUE.

Variety	Date	Temperature	Location of Tissue	Results
Ben Davis apple tree sections...........	Sept. 4,'12	–5	Sections taken at intervals from near the ground to the twigs......	Current season's twigs entirely free from injury. In the older wood injury was slight and confined to cambium and outside part of sap wood. The lowest part of trunk had cambium more severely injured than parts higher up.
Sections from eight year old Improved Janet apple tree...	Sept. 11,'12	–6	Sections taken at intervals from near the ground to the twigs.	Injury most severe in cambium region. Younger stems less browned than older. Sap wood injured in 50% of stems, greatest injury on most rapidly thickening side of stem.
Sections from five year old Improved Janet apple tree....	Sept. 12,'12	–6	Sections taken at intervals from near the ground to the twigs......	Older wood from near ground decidedly more brown than younger wood of twigs. Cortex showed first injury and greatest. Cambium injury slight. Sap wood injury confined to older wood.
Ben Davis apple, seven years old, 2 in. in dia. at crown.............	June 26,'13	–5	Crown (highest point where roots attach 6 in. below surface).........	All sections from lowest to highest injured in cambium. All
Same, 2 in. in dia.....	June 26,'13	–5	6 in. above crown (surface of soil)	

Variety	Date	Temperature	Location of Tissue	Results
Same, 1¾ in. in dia. at crown..........	June 26,'13	–5	12 in. above crown.	above two feet also injured in cortex. All sections above four feet injured in cambium, cortex and sap wood. The crown was hardiest and the higher up from the crown showed the more injury.
Same, 1⅝ in. in dia..	June 26,'13	–5	18 in. above crown.	
Same, 1½ in. in dia...	June 26,'13	–5	24 in. above crown.	
Same, 1¼ in. in dia...	June 26,'13	–5	36 in. above crown.	
Same, 1 in. in dia...	June 26,'13	–4	48 in. above crown.	
Same, ⅝ in. in dia...	June 26,'13	–5	60 in. above crown.	
Same, ½ in. in dia...	June 26,'13	–5	72 in. above crown.	
Ben Davis apple, five years old, 3 in. in dia.........	July 2,'13	–4.5	Crown............	Cambium slightly injured.
Same, 2½ in in...... dia...............	July 2,'13	–4.5	6 in. above crown..	Cambium slightly injured.
Same, 2⅜ in. in dia...............	July 2,'13	–4.5	12 in. above crown.	Cambium injured.
Same, 2 in. in dia...............	July 2,'13	–4.5	18 in. above crown.	Cambium se- severely injured.
Same, 1½ in. in dia...............	July 2,'13	–4.5	24 in. above crown.	Cambium severely injured cortex slightly injured.
Same, 1 in. in dia.	July 2,'13	–4.5	36 in. above crown.	Cambium severely injured cortex slightly injured.
Same, 1 in. in dia.....	July 2,'13	–4.5	48 in. above crown.	Cambium and cortex severely injured.
Same, ¾ in. in dia....	July 2,'13	–4.5	60 in. above crown.	Cambium and cortex severely injured; sap wood slightly injured.
Same, ½ in. in dia....	July 2,'13	–4.5	72 in. above crown.	Cambium and cortex severely injured; sap wood slightly injured.
Same, ¼ in. in dia....	July 2,'13	–4.5	84 in. above crown.	Cambium and cortex severely injured; sap wood slightly injured.
Same, ⅛ in. in dia...	July 2,'13	–4.5	96 in. above crown.	Cambium, cortex and sap wood severely injured.

Variety	Date	Temperature	Location of Tissue	Results
Early Harvest apple, 10 in. in dia..	Sept. 28,'12	–6	Near ground......	Buds largely killed, bark and cambium taken near ground severely injured. The very youngest wood showed little or no injury. In the wood near the ground, the browning was uniformly distributed. In wood higher up the brown was irregular and in spots. In the young wood, cambium appeared normal—only cortex injured.
Same, 7 in. in dia.....	Sept. 28,'12	–6	48 in. above ground	
Same, 3 in. in dia.....	Sept. 28,'12	–6	96 in. above ground	
Same, 1 in. in dia.....	Sept. 28,'12	–6	12 ft. above ground	
Same, ¾ to ¼ in. in dia...........	Sept. 28,'12	–6	15 ft. above ground (includes this year's growth)	
Jonathan apple, four years old......	Oct. 19,'12	–7	At ground........	No injury
Same, four years old..	Oct. 19,'12	–7	12 in. above ground	No injury.
Same, four years old..	Oct. 19,'12	–7	24 in. above ground	No injury.
Same, four years old..	Oct. 19,'12	–7	36 in. above ground	No injury.
Same, four years old..	Oct. 19,'12	–7	48 in. above ground	No injury.
Same, four years old..	Oct. 19,'12	–7	60 in. above ground	No injury.
Same, four years old..	Oct. 19,'12	–7	72 in. above ground	No injury.
Same, four years old..	Oct. 19,'12	–7	84 in. above ground	No injury.
Same, four years old..	Oct. 19,'12	–7	96 in. above ground	No injury.
Jonathan apple, four years old, 2½ in. in dia......	Oct. 23,'12	–9	At ground........	All wood, except ¼ in. in dia. or smaller, injured. The most severely browned section was 2 ft. above ground, at the crotch of a rapidly growing branch. The section at the ground was less injured than the one 1 foot above. Cortex, cambium and sap wood injured.
Same, 2⅛ in. in dia.............	Oct. 23,'12	–9	12 in. above ground	
Same, 1⅝ in. in dia.............	Oct. 23,'12	–9	12 in. above ground	
Same, 1 in. in dia....	Oct. 23,'12	–9	36 in. above ground	
Same, 1⅜ in. in dia.............	Oct. 23,'12	–9	24 in. above ground	
Same, .8 in. in dia....	Oct. 23,'12	–9	48 in. above ground	
Same, .5 in. in dia....	Oct. 23,'12	–9	60 in. above ground	
Same, ¼ in. in dia....	Oct. 23,'12	–9	72 in. above ground	
Same, ¼ in. in dia....	Oct. 23,'12	–9	84 in. above ground	
Same, $\frac{3}{16}$ in. in dia...............	Oct. 23,'12	–9	96 in. above ground (Last 4 new growth)	

Variety	Date	Temperature	Location of Tissue	Results
Jonathan apple, four years old......	Nov. 14,'12	–12	At ground........	Most severely injured. Cambium cortex and sap wood injured.
Jonathan apple, four years old......	Nov. 14,'12	–12	6 in. above ground.	Cambium injured. Cortex slightly injured.
Jonathan apple, four years old......	Nov. 14,'12	–12	12 in. above ground	Cambium injured. Cortex slightly injured.
Jonathan apple, four years old......	Nov. 14,'12	–12	18 in. above ground	Cambium injured. Cortex slightly injured.
Jonathan apple, five years old. (Thickest part of trunk, 3 in. in diameter).......	Jan. 15,'13	–20	At crown.........	All tissue injured severely.
Same..............	Jan. 15,'13	–20	3 in. above crown	All tissue injured.
Same..............	Jan. 15,'13	–20	At level of ground.	Slight injury in bark; none in cambium; sap wood injured.
Same..............	Jan. 15,'13	–20	3 in. above ground	Injury in same tissue as above, but not quite so severe.
Jonathan apple, five years old. (Thickest part of trunk, 3 in. in dia.)...........	Jan. 15,'13	–20	6 in. above ground.	Same as above.
Same..............	Jan. 15,'13	–20	12 in. above ground	Same as above.
Same..............	Jan. 15,'13	–20	18 in. above ground	No injury in cortex or cambium; sap and heart wood slightly injured.
Jonathan apple, five years old. (Thickest part of trunk, 3 in. in dia.)...........	Jan. 20,'13	–15.5	At crown.........	All tissue injured severely.
Same..............	Jan. 20,'13	–15.5	3. in. above crown	All tissue injured slightly less than above.
Same..............	Jan. 20,'13	–15.5	At ground........	Injury in cortex region.
Jonathan apple, five years old. (Thickest part of trunk, 3 in. in diameter).......	Jan. 20,'13	–15.5	3 in. above ground	Slight injury in cortex region.

Variety	Date	Temperature	Location of Tissue	Results
Same...............	Jan. 20,'13	-15.5	6 in. above ground.	Very slight injury in cortex region.
Same...............	Jan. 20,'13	-15.5	12 in. above ground	No injury.
Jonathan apple, five years old......	Mar. 25,'13	-12.5	At crown.........	Severe injury in cortex, cambium and sap wood.
Same...............	Mar. 25,'13	-20	At crown.........	Very severe injury in cortex, cambium, and sap wood.
Same...............	Mar. 25,'13	-12.5	3 in. above crown..	Injury in cortex, cambium and sap wood less severe than at crown
Same...............	Mar. 25,'13	-20	3 in. above crown..	Less severe injury than at crown.
Same...............	Mar. 25,'13	-12.5	6 in. above crown..	Very slight injury in cortex and cambium.
Same...............	Mar. 25,'13	-20	6 in. above crown..	Less severe injury than above in same regions.
Same...............	Mar. 25,'13	-12.5	3 in. above ground.	No injury.
Same...............	Mar. 25,'13	-20	3 in. above ground.	Very slight injury in cortex.
Same...............	Mar. 25,'13	-12.5	6 in. above ground.	No injury.
Same...............	Mar. 25,'13	-20	6 in. above ground.	No injury.
Same...............	Mar. 25,'13	-12.5	9 in. above ground.	No injury.
Same...............	Mar. 25,'13	-20	9 in. above ground.	No injury.
Same...............	Mar. 25,'13	-12.5	12 in. above ground	No injury.
Same...............	Mar. 25,'13	-20	12 in. above ground	No injury.
Same...............	Mar. 25,'13	-12.5	18 in. above ground	No injury.
Same...............	Mar. 25,'13	-20	18 in. above ground	No injury.

It will be seen that the part of the trunk that most slowly develops hardiness on approach of winter is that near the surface of the ground and near the junction of rapidly growing limbs. All the tissue at the lower part of the tree is more tender in early winter than is the upper portion. Of course this might not be true on other seasons. The autumn of 1912, however, was a normal one, the wood apparently going into winter in a well ripened condition. In June and early July the wood in the upper portion of the tree is most tender. It is also interesting to note that in June and July when the

tissue is generally most tender, the tissue near the base of the tree is most hardy.

Selby[1] observed that the great tenderness in the early part of the winter is probably due to a greater moisture content. He observed that the cambium in winter during the time when plants are very hardy, is in a much dried out condition and in normal seasons has to some extent reached this condition by the time of the early freezes, but in seasons like that one preceding the winter of 1903-4 it is still in a somewhat succulent condition when the early freeze comes.

It is well known that seeds in a dry condition will withstand very much lower temperature than when they have absorbed moisture. Thus Schaffnit[2] reduced the germination percentage of wheat from 100 to 40 by soaking it in water for eight hours at room temperature. In twigs it is probable that a dry condition is essential to the hardiness of the cambium. Shutt[3] and also Allen[4] seem to find a relation between moisture content and hardiness of apple twigs. However, it does not seem that the increase in hardiness of other tissue than cambium, at least of cortex, during early winter can be explained by a decreasing moisture content.

During the winter of 1912-13, beginning November, twigs of apple, peach, plum and cherry were scraped, the cortex ground, weighed carefully, evaporated to dryness in a water bath (to which later glycerine was added to raise the boiling point in the water jacket and thus raise the temperature), and weighed at intervals of two to three days until a constant weight was reached. Samples were taken again in January and again in May. No samples were taken when the tissue was frozen, since then the percentage of moisture would be smaller. The evaporated moisture could not be replaced from below. The following table gives the results:

[1]Ohio Agr. Exp.Sta. Bul. 192, 1908. (Bibl. No. 101).

[2]Mitt. Kaiser Wilhelm Inst. Landw. zu Bromberg, Vol. 3, No. 2, pp. 93-113, 1910. (Bibl No. 98).

[3]Procs. and Trans. Roy. Soc. Canada, ser. 2, Vol. 9, pp. 149-153. (Bibl. No. 104.)

[4]Master's Thesis, Iowa Agr. Exp. Sta. (Bibl. No. 2).

TABLE 25. SHOWING THE MOISTURE CONTENT OF THE CORTEX IN NOVEMBER, JANUARY AND MAY.

Material	Date	Weight Fresh Sample. Grams	Weight Dry Sample. Grams	Per-cent-age Water	Average Percent-age Water
Jonathan apple, entire twig.	Nov. 15,'12	36.45	17.15	52.95	
Jonathan apple, entire twig.	Nov. 15,'12	35.82	16.75	53.52	53.24
Elberta peach, entire twig....	Nov. 15,'12	26.10	12.35	52.61	
Elberta peach, entire twig....	Nov. 15,'12	28.84	13.85	51.98	52.33
Jonathan apple, buds, bark and cambium............	Nov. 27,'12	30.05	13.60	54.70	
Jonathan apple, buds bark and cambium............	Nov. 27,'12	29.95	13.40	55.60	55.2
Elberta peach, buds, bark and cambium...........	Nov. 27,'12	30.15	13.25	56.00	
Elberta peach, buds, bark and cambium............	Nov. 27,'12	30.00	13.05	56.50	56.3
Jonathan apple, buds bark and cambium............	Jan. 11,'13	25.00	12.25	51.00	
Jonathan apple, buds, bark and cambium............	Jan. 11,'13	25.00	12.10	51.60	51.3
Elberta peach, buds, bark and cambium............	Jan. 11,'13	25.00	10.65	57.40	
Elberta peach, buds, bark and cambium............	Jan. 11,'13	25.00	11.10	55.60	56.5
Jonathan apple, entire twig.	May 3,'13	20.00	8.96	55.50	
Jonathan apple, entire twig.	May 3,'13	20.00	8.80	56.80	56.15
Elberta peach, entire twig....	May 3,'13	20.00	9.15	54.25	
Elberta peach, entire twig....	May 3,'13	20.00	9.00	55.00	54.63

It will be seen that there is no constant difference in moisture content of the twig cortex from November to May. The difference in the hardiness of the cortex can not be accounted for by the difference in the moisture content, but must be accounted for in some other way. The suggestion is sometimes made that a greater sap density of the twig and other tissue during winter might account for this greater hardiness. It was not possible with our apparatus, at least, to secure sap from the sap wood. The cortex, however, shows this increase in hardiness to a slightly greater extent than does the sap wood. The following table shows the cortex sap density of apple and peach twigs at various seasons of the year, through a period of three years:

TABLE 26. SHOWING SAP DENSITY OF APPLE AND PEACH TWIGS THROUGHOUT THE YEAR AS MEASURED BY THE FREEZING POINT DEPRESSION.

Date	Elberta peach	Jonathan apple	Gano apple
	Depression	Depression	Depression
January	1.902	2.054	1.630
February	1.841	2.170	No data
March	1.758	No data	1.616
April	1.765	1.055	.949
May	1.055	0.915	1.085
June	1.263	1.415	1.289
July	1.252	1.500	1.469
August	1.652	1.623	1.570
September	1.748	1.605	1.690
October	1.743	1.892	1.728
November	1.765	1.924	1.665
December	1.694*	2.016	No data

*Only one depression taken in December.

It will be seen that while the sap density of the cortex of winter twigs is much greater than that of early summer twigs, yet it is not appreciably greater than that of twigs in late September and October, when the tissue is still considerably more tender than in December and January. Some may suspect that the low sap density of the early summer twigs may be due to their young and somewhat succulent condition. It may be said, however, that the density of the cortex of these young twigs is generally greater than that of any other tree tissue except the leaves. (Data to be published in another bulletin). It would seem certain then that while a part of the increased hardiness of tree tissue in winter may possibly be accounted for by the greater sap density, not all of it can; certainly not the greater hardiness of December tissue over that of October.

In the case of plants killing at as low temperature as those at which winter twigs kill, it seems possible that the sap solute, if it remains in solution, may tend to keep a small amount of water unfrozen and thus protect the protoplasm to some extent. If this should be true, the eutectic point of the sap solute would play a very important part in determining the amount of killing. Some efforts were made to determine whether or not there may be changes in the sap solute as winter comes on that give it a lower eutectic point. Just at the time of leaf fall or slightly before, twigs had the cortex scraped

from them and the sap expressed in large enough quantities that it could be evaporated down to one-fourth to one-eighth of its volume and leave enough for freezing point determinations with a Beckmann thermometer. The evaporating was done in a dry oven where the temperature never was above 50° C. The evaporating was done in broad, shallow dishes and was generally accomplished in one day. There was apparently no fermentation. In all cases sap taken in October or early November would be thick and gummy long before it could be concentrated to one-sixth of its original volume. It was noticed that it was very difficult indeed to filter the sap from the twigs in autumn or very early winter, while sap taken in December or January or later, filtered much more easily and could be concentrated to one-sixth to one-eight of its volume. In this case it would stay in solution at temperatures as low as could be secured with salt and ice; that is, temperatures low enough to kill many peach buds, indicating that there is certainly a probability that at least a part of the sap solute remains in solution at a temperature low enough to hold water unfrozen to protect the protoplasm. Of course in the earlier season the solidifying of the liquid may be due to colloidal substances in large quantities, and it is entirely possible that the solute had just as low an eutectic point. It was not possible to determine the eutectic point by keeping temperature records since no apparatus was available other than the Beckmann thermometer which could not be used without changing the setting several times, for such low temperature.

It would seem highly probable that, except in the case of cambium, the additional hardiness acquired by the different tissues of the tree as they pass into winter, is a change in the protoplasm such that it can withstand the great loss of water rather than a change in the percentage of moisture or in sap density. It is also possible that changes in the sap solute that lower its eutectic point may occur and that these may increase the resistance to cold by holding water unfrozen to protect the protoplasm from too complete desiccation at lower temperatures.

Rate of Growth and Hardiness. At the time of most rapid growth of deciduous plants in early summer they are generally most tender. Whether this is because they are furthest from the condition of maturity they acquire in autumn and early winter, or because of the very low sap density at this time, it is not easy to say. In some cases the young tissue is most hardy. Thus Goeppert found young leaves more hardy than older ones. Apelt[1] found the

[1]Cohn. Beitrage z. Biol. d. Pfl. Vol. 9, p. 215. (Bibl. No. 3).

young outer ends of potato shoots to withstand lower temperatures than would the older basal portion. Rein[1] found young onion leaves more hardy than older ones. Winkler[2] found young one-year-old needles of evergreens more hardy than older ones. Shumacher[3] found young yeast cells more hardy than older ones. Fisher[4] found newly formed colloids to regain their normal characteristics after being exposed to a low temperature that would irreversibly change older colloids. On the other hand Bartetzko[5] found that young cultures of *Aspergillus niger* would not withstand as low temperatures as would older ones. It seemed worth while to make some freezings to determine whether or not plant tissues making rapid growth are generally frozen to death at higher temperatures than are tissues growing more slowly. Leaves of various plants were used, leaves that were certainly full grown—in case of those from fruit trees—and leaves that had apparently ceased growing, in case of plants like lettuce, cabbage, kale, etc., were frozen at the same time with young rapidly growing leaves from near the growing tips of the stem. The following table gives the results:

[1]Zeits. f. Naturw. Vol. 80 (1908) p. 1. (Bibl. No. 92).
[2]Jahrb. f. Wiss. Bot. Vol. 52, 1913, pp. 467-506. (Bibl. No. 121).
[3]Sitzungsber der Math. Phys. Klasse d. Wiener Akad. d. Wiss. Alt. 1, 1874. (Bibl. No. 103).
[4]Beitr. Biol. der Pfl. Vol. 10, pp. 133-234, 1911. (Bibl. No. 40).
[5]Jahrb. f. Wiss. Bot. Vol. 47, pp. 57-98 (1911). (Bibl. No. 8).

TABLE 27. SHOWING THE RELATIVE HARDINESS OF YOUNG RAPIDLY GROWING LEAVES AND OLD MATURE LEAVES.

Material	Date	Temperature	Results
Jonathan apple twigs thawed slowly......	May 17,'13	-4	2 small terminal leaflets of each of the 4 twigs were injured.
Jonathan apple twigs thawed rapidly.....	May 17,'13	-4	2 twigs had 4 terminal leaflets injured; 1 twig had 5 end leaves injured; 1 twig had 6 end leaves injured. All mature leaves were uninjured.
Jonathan apple.......	May 24,'13	-4	Slight injury in terminal part. Mature leaves uninjured.
Young Jonathan apple..............	June 7,'13	-5	Terminal leaflets injured. Mature leaves green and turgid: slight injury being confined to leaf veins. In terminals, 2 to 5 in. of the twigs, cortex, cambium, sap wood and pith were severely injured, cortex and pith being hardier. Older portion was much hardier.
Jonathan apple.......	June 12,'13	-4.5	In freezer with peach on same date. Injury not so great as that to peach, but younger terminal leaves showed considerable injury while older leaves at the base of the twigs were uninjured.
Salway peach.........	May 24,'13	-4	Very slight injury in terminal part. Mature leaves uninjured.
Elberta peach twigs....	June 7,'13	-5	All terminal buds killed. Mature leaves, including those below 2 in. of terminal, had mid-ribs and veins killed, with other tissues apparently uninjured. Small leaves adjoining large old leaves uninjured. In terminal 3 in. all tissues were injured. Of the remaining portion only the cambium showed severe injury.
Elberta peach........	June 12,'13	-4.5	Slowly and rapidly growing twigs were used. Only 2 to 3 terminal leaves of the slowly growing twigs showed injury, while on the rapidly growing twigs 7 to 8 terminal leaves were entirely killed. Oldest leaves at base of all twigs were uninjured.
Grape shoots.........	May 24,'13	-4	Youngest 10 leaves of 8 in. shoot dead. Mature ⅓ of 18 in. shoot uninjured.

Material	Date	Temperature	Number Leaves	Percentage Surface Injured	Percentage Leaves all Killed	Depression
Black Seeded Simpson lettuce young leaves...	June 11,'13	-4	18	33.3	16.6	0.520
Black Seeded Simpson lettuce old leaves......	June 11,'13	-4	40	79.3	70.0	0.575
Black Seeded Simpson lettuce young leaves...	June 12,'13	-4	12	83.3	50.0	
Black Seeded Simpson lettuce old leaves......	June 12,'13	-4	17	30.8	11.7	
Tomato leaves, old and turgid................	June 24,'13	-3	32	72.65	50.0	
Tomato leaves, young and turgid................	June 24,'13	-3	30	63.30	30.0	
Flat Dutch Cabbage, young leaves..........	June 13,'13	-5	10	100.0	100.0	
Flat Dutch Cabbage, old leaves............	June 13,'13	-5	4	100.0	100.0	
Flat Dutch Cabbage, young leaves..........	June 14,'13	-3	3	0.0	0.0	
Flat Dutch Cabbage, old leaves............	June 14,'13	-3	4	87.4	75.0	
Red Rock Cabbage young leaves..........	July 1,'13	-4	5	100.0	100.0	
Red Rock Cabbage, old leaves................	July 1,'13	-4	5	95.0	80.0	
Cowpeas..............	June 14,'13	-3	6 (plants)	Leaves all dead; stems alive. Old and young leaves equally injured. Young stems dead; old stems alive.		
Young tobacco leaves, 2-12 cm. in length.....	July 12,'13	-2	5	20.0		
Old tobacco leaves, 20-40 cm. in length..........	July 12,'13	-2	5	75.0		
Young tobacco leaves, 2-12 cm. in length.....	July 12,'13	-2.5	5	75.0		
Old tobacco leaves, 20-40 cm. in length..........	July 12,'13	-2.5	5	90.0		

In case of apples and peaches the young leaves are uniformly more easily killed, while in the case of some of the succulent plants there is little or no difference. In case of lettuce the young leaves are certainly the more resistant. The density of the sap of the old peach leaves was such that an average of ten freezing point determinations gave a depression of 1.931 while for the young leaves the depression was 1.663. With the Jonathan apple, the depression for old leaves was 1.849 while for young leaves it was 1.202. With these leaves then it seems that the greater sap density will explain the greater

hardiness of the older leaves. In fact the following table, giving results where twigs with young leaves were placed in cane sugar and glycerine solutions, indicates that increasing the sap density of the young leaves to that of the old leaves will increase their hardiness to nearly that of the old leaves.

TABLE 28. SHOWING RELATIVE HARDINESS OF YOUNG AND OLD APPLE LEAVES AND OF YOUNG LEAVES THAT HAD ABSORBED GLYCERINE AND CANE SUGAR.

Age of Leaf	Treatment	Date	Temperature	Number of Leaves	Percentage all Killed	Percentage Surface Killed	Depression
Old....	Water 30 hrs....	July 8,'13	-4	20	0.0	55.00	1.480
Young.	Water 30 hrs....	July 8,'13	-4	26	50.0	82.70	1.340
Young.	Cane sugar 3 hrs (10%)........	July 8,'13	-4	18	11.1	34.90	1.818
Young.	10 %Glycerine 3 hrs..........	July 8,'13	-4	26	0.0	5.70	3.400
Old.....	Fresh..........	July 12,'13	-4	20	0.0	17.50	.....
Old....	Water..........	July 12,'13	-4	20	0.0	28.70	1.540
Young.	Fresh..........	July 12,'13	-4	19	26.3	48.70	.....
Young.	Water..........	July 12,'13	-4	21	71.4	91.70	1.230
Young.	Cane Sugar.....	July 12,'13	-4	22	27.2	48.90	1.792
Young.	Glycerine.......	July 12,'13	-4	22	22.7	32.90	3.400
Old....	Fresh..........	July 12,'13	-7	20	35.0	46.20	.....
Old....	Water..........	July 12,'13	-7	20	80.0	85.00	1.540
Young.	Fresh	July 12,'13	-7	22	77.7	94.30	.....
Young.	Water..........	July 12,'13	-7	22	100.0	100.00	1.230
Young.	Cane sugar......	July 12,'13	-7	19	57.9	89.40	1.792
Young.	Glycerine.......	July 12,'13	-7	27	44.1	69.40	3.400

In case of lettuce, however, the depression for old leaves was 0.575, and for young leaves 0.520, and the young leaves are the most resistant to the low temperatures. It is possible that the waxy or oily covering on the surface of the young lettuce leaves increased their resistance to low temperatures. In our experience leaves and fruits dipped in glycerine or paraffine have been uniformly more resistant than have tissues not so treated.

EFFECT UPON HARDINESS OF PREVIOUS EXPOSURE TO TEMPERATURE SLIGHTLY ABOVE THE KILLING TEMPERATURE.

Closely related to the questions of the relation of maturity to hardiness, and the relation of the rate of growth to hardiness, is the relation of exposure to low temperature, above that at which the plants may kill, to hardiness. In fact these problems are so intertwined that it is difficult, if not impossible, to separate them. Thus in case of the greater hardiness of roots kept in cold storage as compared with those kept in warmer places, unquestionably maturity plays a large part but it is not impossible that exposure to cold also had its effect. However, by referring to Table 14 it will be seen that there was little difference among the killing of roots kept in cold storage at a temperature of 31° F., those kept frozen up in the soil, and those kept at a higher temperature in our basement storage room. The relation of exposure to cold to hardiness of winter buds and wood may also be confused with the rate of temperature fall. This problem will be discussed for peach buds in a later part of this paper. In case of some succulent plants, however, the temperature at which they grew must exert an influence on their hardiness. Thus when cabbage, kale and lettuce were grown out of doors in late autumn or early winter, their hardiness was increased over those grown in the greenhouse more than can be explained by the increased sap density. At least their hardiness was increased more than the same increase in sap density brought about by any other means would increase it. When these plants were grown out of doors in early spring or late autumn, it required a much lower temperature to kill them than was required in June or July. On the other hand, plants like tomatoes or cowpeas are influenced in hardiness but slightly by the temperature at which they grow.

Goeppert[1] found little increase in hardiness due to continuous exposure to low temperature with tender tropical plants, but there was such adaptation with more resistant plants. Apelt[2] found that potatoes kept at a temperature of 22.5° C. four to seven weeks were killed at -2.14° C. while potatoes kept at 0° C. for the same length of time killed at -3.08° C. Rein[3] found that a rather large list of very tender plants kept at a temperature of 8° C were not apprecia-

[1]Ueber die Wärmeentwickelung in dem Pflanzen, etc, book, 1830. (Bibl. No. 44).
[2]Cohn's Beitrage z. Biol. d. Pfl. Vol. 9, 1907, p. 215. (Bibl. No. 3).
[3]Zeits. f. Naturw. Vol. 80, 1908, p. 1. (Bibl. No. 92).

bly hardier than when kept at a temperature of 20° C., while more resistant plants were considerably more hardy when kept at a low temperature. Fisher[1] found that it required a lower temperature to change the nature of colloids like starch paste that had been kept at low temperatures than to change the nature of colloids kept at a high temperature.

Relative Hardiness of Different Tissues at Different Seasons of the Year. When trees are in a rapidly growing condition, apparently the most tender part of the wood tissue is the cambium and the young cortex, and sap wood cells. However, in winter after the wood has reached its greatest maturity, this is not the case. In fact when severe cold comes, the first tissue to kill seems to be the pith in the case of young twigs, and there will be browning in the sap wood and part of the cortex. In case of the cortex the browning is generally worse in the outer or older cells. This was observed by Eustace[2] on peach trees following the winter of 1903-04. We have often observed the same in artificial freezings we have made, as well as on peach trees badly injured in winter. Peach trees so injured that the sap wood seemed practically all browned have, under favorable conditions, had the cambium form new layers of sap wood surrounding this wood. This injured wood soon becomes entirely dead and the tree depends on the new sap wood formed for conductive tissue. We have also observed dead areas of bark following the winter of 1911-12 when underneath there was healthy new bark and healthy cambium. In these cases, at least, the cortex was more tender than the cambium.

The fruit buds of the peach in late summer during the growing season are generally about as hardy as the cortex and cambium, or sap wood of the twigs, though perhaps slightly less hardy than the same tissues in older wood; while in winter under normal conditions, at least with peaches, the fruit buds are generally somewhat less hardy than any of the wood tissue, with the possible exception of the pith cells. However, in the case of a cold wave that comes on very gradually, say during a period of two or three weeks with a very cold night at the end, some of the buds may survive a temperature low enough to kill the sap wood badly. Thus following the winter of 1904-5, when the temperature at Columbia went to -25° C. after several weeks of very cold weather, nearly all of the peach trees had a few live buds left while the wood was very badly damaged; and in the case of peaches in New York following the winter of 1903-04,

[1]Beitr. Biol. der Pfl. Vol. 10, pp. 133-234, 1911. (Bibl. No. 40).
[2]New York (Geneva) Agr. Exp. Sta. Bul. 269, 1905. (Bibl. No. 38).

Eustace observed that the trees may be badly injured and yet enough fruit buds left for a full crop of fruit. This last, however, was the condition when the tissue of the tree had not reached the proper maturity before the cold period came. The fruit buds seem, sometimes at least, to reach about their maximum condition of maturity more quickly than wood tissues, especially that near the base of the tree. Tables 23 and 24 give some information as to the relative hardiness of other tissues, and the following table gives the result of some additional freezings where buds were frozen in comparison with other tissues:

TABLE 29. SHOWING RELATIVE HARDINESS OF DIFFERENT TISSUE, INCLUDING BUDS, AT DIFFERENT SEASONS OF THE YEAR.

Variety	Date	Temperature	Results
Elberta peach twigs...	July 15,'13	-6	23 buds, 78.3% killed. 10 twigs 7 injured in cambium. 3 in cambium and cortex.
Elberta peach twigs...	July 16,'13	-5	50 buds, 100% killed. 20 twigs, all injured in cambium and cortex.
Elberta peach twigs, buds and sections of wood..............	July 28,'13	-5	37 buds, 100% killed. Roots, dead in cambium and cortex. Wood just above ground, severely injured in cortex and cambium. 4 feet from ground, same as above. This years' growth, same as above. Sap wood and pith of youngest portions dead.
Champion peach twigs 10 in. long.........	July 29,'12	-5	95% of leaf surface dead. Cortex injured 6 in. back of terminal. Cambium, pith and sap wood injured to 8 in. back of terminal.
Belle of Georgia peach tree, five years old; sections of trunk and limbs..........	Aug. 29,'12	-5	Buds, 100% killed. Young sap wood and cambium killed in all sections. Least injury to bark was in three year old wood. Bark, cambium and sap wood killed in twigs.
Elberta peach tree, buds and twigs and sections of trunk and limbs..........	Sept. 14,'12	-5	Buds 100% injured. Bark cambium and outer portion of sap wood injured in all cases.
Elberta peach twigs (one year old)......	Oct. 5,'12	-5	Buds 90, 91% dead. Cambium and cortex injured except at base of one twig. Sap wood injured only in terminal part twig.
Elberta peach twigs...	Nov. 1,'11	-9	104 buds; 63% dead. 33 twigs; 60.6% killed in cambium, other tissue not injured.
Elberta peach twigs...	Dec. 7,'12	-16	Injury confined to shoulder below bud and pith region. Buds proper, uninjured.

Variety	Date	Temperature	Results
Elberta peach twigs...	Mar. 23,'13	–18	100 buds, 88% killed. Injury to wood confined in all cases to sap wood and pith.
Rice's Seedling peach twigs........	Mar. 23,'13	–18	138 buds, 44.2% killed. Injury to wood confined in all cases to sap wood and pith. Injury less than to Elberta.
Late Duchess apple twigs.......	July 15,'13	–6	20 buds, 70% killed. 4 twigs, no injury.
Jonathan apple twigs.	July 16,'13	–5	29 buds, 86.2% killed. 9 twigs, no injury.
Jonathan apple twigs..	July 16,'13	–5	24 buds, 58.3% killed. 11 twigs, no injury.
Young apple twigs, variety not given...	July 27,'12	–5	12 buds, 100% killed. Cortex browned in places, especially around the buds. Cambium dead in region of annual ring and terminal of year's growth. Pith dead in region of annual ring.
Young apple twigs, variety not given....	July 27,'12	–5	Leaves practically all injured. Bark killed about 7 in. back from terminal. Cambium killed about 7 in. back from terminal. Sap wood killed 5 to 6 in. back from terminal. Pith killed 4 to 5 in. back from terminal.
Jonathan apple twigs and wood from three-year old Jonathan tree.........	July 28,'13	–5	44 buds, 70% dead. Roots, cambium and cortex injured throughout. Wood, sections just above ground and 3 feet above dead in cambium and cortex. This year's growth injured in cambium and cortex in older parts, and all tissue dead at tips.
Jonathan apple stems from ⅛ in. to 1 in. in diameter........	Aug. 15,'12	–5	Cortex and cambium injured slightly in all samples. Sap wood and pith not injured. No marked difference between the different diameters.
Dyehouse cherry young and old wood	July 28,'13	–5	40 buds, 100% killed.
Cherry twigs.........	Aug. 13,'12	–6	25 out of 36 buds killed. Some buds at base of new twigs and on spurs on old wood alive. Leaves all partially injured; only 25% entirely killed. Youngest wood injured worst. Slight injury in cambium and cortex. No injury to sap wood of two year twigs or older.

By referring to this table and to Tables 22, 23 and 24, it will be seen that the fruit buds are in all seasons apparently less hardy than any other tissue, except the pith and the tissue at the base of the buds, and in early winter the wood at the surface of the soil.

The most tender tissue of the tree is in the roots. Thus in case of the tree frozen July 2, 1913 (Table 24) when the tissue above ground is most tender, the roots were injured in the cambium at -3.5° C., and severely injured in cambium, cortex and sap wood at -4.5° C. Goeppert[1] found that the roots of hardy plants kill at a temperature of from -10° to -15°. A study of the killing temperatures of roots of various fruit trees has been made at this station. In the summer there is not so large a difference between the killing temperature of roots and other tissue. However, the roots do not seem to develop as great maturity as the tissue above ground. The following table shows the results with freezing the roots of trees in summer and winter seasons:

TABLE 30. SHOWING KILLING TEMPERATURE OF APPLE, PEACH, PLUM AND PEAR ROOTS.

Kinds of Roots	Date	Temperature	Results
Two-year Ben Davis apple roots.........	June 23,'13	–5	Cambium only injured in larger roots. Cortex also injured in roots ¼ in. in diameter. In 2 out of 4 cases, crown uninjured. In other 2 cases there was slight injury to cambium at crown.
Seedling two-year old apple stock roots....	June 24,'13	–5	No injury at all..................
Two-year Ben Davis apple roots.........	June 25,'13	–3	No injury in roots above ¼ in. in diameter. Wood just above crown was injured in cambium.
Seedling apple stock roots..............	Aug. 20,'12	–6	Cortex and cambium region all dead.
Seedling apple stock roots..............	Aug. 22,'12	–5	Cortex and cambium injured, but less severely than above.
Two-year Ben Davis apple roots.........	Dec. 7,'12	–6.5	Cortex, cambium and wood injured.
Two-year Ben Davis apple roots.........	Dec. 7,'12	–4	One small root injured.
Seedling apple stock roots from basement since December 20th..............	Jan. 13,'13	–8	Injury confined to cortex region.'
Seedling apple stock roots from basement since December 20th..............	Jan. 17,'13	–9	Injury slight and confined to cortex region.
Apple stock buried 5 in. below surface outside since Jan. 8th..............	Mar. 8,'13	–10	One root browned and the other not injured....................

[1]Ueber die Wärmeentwickelung in dem Pflanzen, etc., book, 1830. (Bibl. No. 44).

Kinds of Roots	Date	Temperature	Results
Apple stock buried 5 in. below surface outside since Jan. 8th	Mar. 8,'13	-14	All roots browned
Two year Ben Davis apple roots	Mar. 24,'13	-10	No injury in first 2 inches; cambium injury throughout remainder. Cortex showed next greatest injury, and in smaller roots sap wood also injured.
Seedling peach roots	June 25,'13	-3	Entire system injured in cambium and sap wood. Injury slightly less in crown.
Seedling peach roots	June 25,'13	-5	All roots very severely injured in cambium and cortex and portion of sap wood. Crown as severely injured as terminal roots. Stem just above ground injured in cortex and cambium.
Elberta peach roots	Oct. 14,'11	-9.5	5 roots; 100% dead.
Elberta peach roots	Oct. 18,'11	-5.5	13 inches of root length; 100% dead.
Elberta peach roots	Oct. 19,'11	-4.5	30½ inches of root length; 100% injured, smaller roots injured worst.
Seedling peach roots	Dec. 7,'12	-6.5	Cortex, cambium and wood injured.
Seedling peach roots	Dec. 7,'12	-4	Slight injury.
Marianna plum root	June 25,'13	-5	Largest root injured severely in cortex. No apparent difference between crown and remainder of root system.
Marianna plum roots.	June 26,'13	-3	Crown 1 in. in diameter shows slight injury in cambium; 3-10 in. down cortex injured also; sap wood also injured towards tips.
Marianna plum roots	Dec. 7,'12	-4	Slight injury in cortex.
Marianna plum roots	Dec. 7,'12	-6.5	Cortex, cambium and sap wood injured.
Kieffer pear roots	Oct. 10,'11	-5.5	14½ inches; 65.5% dead.
Kieffer pear roots	Oct. 14,'11	-9.5	5 roots; 100% dead. Twigs at same temperature, cambium only killed.
Kieffer pear roots	Oct. 19,'11	-4.5	33½ inches; 100% injured. Killing more severe in younger roots some distance from the trunk than in larger ones.
Kieffer pear roots	Mar. 27,'13	-10	Injury grading from none in crown to injury of all tissues where diameter of root was not greater than 3-10 inch.

It will be seen that the killing temperature of the roots varies from about -3° C. in summer when most tender to about -12° C. in late winter with rather rapid freezing. The roots are certainly as hardy in March as in January. Thus they are later in becoming tender in spring than are twigs. They are still very tender in autumn

when tissue above ground has begun to increase rapidly in hardiness. This may be because the soil is still too cold for growth well up into March, generally, and continues warm late in autumn.

The following table gives the result of freezing young apple roots (stock) kept in cold storage at a temperature of 31° to 32° F., in the earth frozen up where the temperature varied from the freezing point to 39° F., and others kept in greenhouse conditions whereby they started into growth, and others kept in basement storage room at a temperature varying from 4° C. to 15° C. from January 8, 1913 to February 16, 1913, the date of freezing.

TABLE 31. SHOWING RELATIVE RESISTANCE TO LOW TEMPERATURES OF APPLE ROOTS KEPT IN DORMANT CONDITION AS COMPARED WITH THOSE IN A GROWING CONDITION.

Kind of Root	Temperature	Number of Roots	Greenhouse	Frozen soil	Basement Storage Room	Cold Storage
Crown cut diameter $\frac{3}{10}$ in.....	–6	2	No injury..	No injury	No injury	No injury
Second cut diameter ¼ in.....	–6	2	No injury..	No injury	No injury	No injury
Third cut diameter $\frac{1}{6}$ in.	–6	2	A. Cortex and cambium brown. B. Cambium brown.....	No injury	No injury	No injury
Fourth cut diameter ⅛ in......	–6	2	All tissues injured....	No injury	No injury	No injury
Crown cut diameter $\frac{3}{10}$ in......	–7.5	2	A. Cortex and cambium brown. B. Cambium brown.....	No injury	No injury	No injury
Second cut diameter ¼ in.....	–7.5	2	A. Cortex and cambium brown. B. Cambium brown.	No injury	No injury	No injury

Kind of Root	Temperature	Number of Roots	Greenhouse	Frozen soil	Basement Storage Room	Cold Storage
Third cut diameter ⅕ in......	−7.5	2	All tissues injured......	No injury	No injury	No injury
Fourth cut diameter ⅛ in......	−7.5	2	All tissues injured....	Cambium brown... B. No injury.	Cambium brown. B. No injury.	No injury
Crown cut diameter 3/10 in......	−9	2	All tissues injured.....	No injury	No injury	ACambium injured. B. No injury.
Second cut diameter ¼ in.....	−9	2	All injured..	No injury	ACambium injured. BCambium and cortex injured.	ACambium injured. BCambium and cortex injured.
Third cut diameter ⅕ in......	−9	2	All injured..	Cambium injured.	All injured	All injured
Fourth cut diameter ⅛ in......	−9	2	All injured.	Cambium and cortex injured.	All injured	All injured

Stored Dec. 20th. The second, third and fourth cuts are sections of the stock of equal length below the crown.

TABLE 31a. SHOWING RELATIVE RESISTANCE TO LOW TEMPERATURES OF APPLE ROOTS KEPT IN DORMANT CONDITION AS COMPARED WITH THOSE IN A GROWING CONDITION.

Kind of Root	Temperature	Number Roots	Outside	Greenhouse
Crown cut diameter $\frac{5}{16}$ to $\frac{1}{4}$ in.	-4	2	No injury....	No injury....
Lower cut diameter $\frac{1}{4}$ to $\frac{3}{16}$ in.	-4	2	No injury....	No injury....
Crown cut diameter $\frac{5}{16}$ to $\frac{1}{4}$ in.	-6	2	No injury....	No injury....
Lower cut $\frac{1}{4}$ to $\frac{3}{16}$ in. in diameter	-6	2	No injury....	No injury....
Crown cut diameter $\frac{5}{16}$ to $\frac{1}{4}$ in.	-8	2	No injury....	One root very brown; other slightly.
Lower cut diameter $\frac{1}{4}$ to $\frac{3}{16}$ in.	-8	2	No injury....	Both roots brown in cortex and cambium.
Crown cut diameter $\frac{5}{16}$ to $\frac{1}{4}$ in.	-10	2	No injury.....	
Lower cut diameter $\frac{1}{4}$ to $\frac{3}{16}$ in.	-10	2	One root brown; other not injured.	
Crown cut diameter $\frac{5}{16}$ to $\frac{1}{4}$ in.	-14	2	All browned...	
Lower cut diameter $\frac{1}{4}$ to $\frac{3}{16}$ in.	-14	2	All browned...	

Stored January 8, 1913.

TABLE 31b. SHOWING RELATIVE RESISTANCE TO LOW TEMPERATURES OF APPLE ROOTS KEPT IN DORMANT CONDITION AS COMPARED WITH THOSE IN A GROWING CONDITION.

Where Stored	Largest Diameter	Length	Temperature.	Results.
Outside.......	.3 in......	9+ in...	-9	No injury in first 6 in. from top. Cambium and cortex slightly injured in remainder.
Outside.......	.3 in......	9+ in...	-9	Cambium injured slightly in last 7 inches.
Outside.......	.3 in......	8+ in...	-9	Cambium injured slightly in last 7 in; cortex also injured in last 5 in; sap wood injured only at terminal.
Outside.......	.3 in......	8+ in...	-9	Cambium injured slightly in last 7 in; cortex injured in last 5 in; sap wood injured at terminal.
a)Cold Storage	.3 in......	7 in.....	-9	No injury in first 5 in; slight injury in cortex and cambium in remainder.
Cold storage...	.25 in......	9 in.....	-9	No injury in first 6 inches. Cambium injured in remainder.
Cold Storage..	.35 in.....	8 in.....	-9	Cambium injury throughout.
Cold storage...	.3 in......	7 in.....	-9	Slight injury in cambium throughout.
b)Greenhouse..	.3 in......	12 in.....	-9	Slight injury in cambium throughout.
Greenhouse....	.25 in.....	10 in.....	-9	Very slight injury in cambium in first 5 inches. Cambium and cortex injury throughout the remainder.

a) In cold storage since January 12, 1913.
b) In greenhouse since January 12, 1913.

TABLE 31c. SHOWING RELATIVE RESISTANCE TO LOW TEMPERATURES OF APPLE ROOTS KEPT IN DORMANT CONDITION AS COMPARED WITH THOSE IN A GROWING CONDITION.

Where Stored	Temperature	Results
Greenhouse since March 29, 1913	-7.5	Injured in cortex, cambium and sap wood throughout.
Cold storage since April 1, 1913..	-7.5	Cambium injured throughout entire root. Cortex showed injury only in the terminal 3 to 5 inches. No injury in sap wood.
Basement store room since December, 1912................	-7.5	Slight injury.

It will be seen that there is little difference between the killing temperature of those in storage and those in a storage room at 10 to 37° F. higher temperature and those kept out in the soil. However, those that were in a growing condition were less hardy but with nothing like the difference that would be observed in the case of twigs kept under similar conditions. The reason the roots kept in the basement store room were more hardy than we should expect, is possibly because of their being kept in a somewhat dry condition.

In the case of young peach roots, those kept in cold storage showed a greater hardiness than those kept in the soil outside. Some growth may have taken place in the roots kept out in the soil. The following table gives results of the freezing of peach roots:

TABLE 32. SHOWING RELATIVE RESISTANCE TO LOW TEMPERATURE OF YEAR-OLD SEEDLING PEACH ROOTS GROWING AND IN A THOROUGHLY DORMANT CONDITION.
DATE OF FREEZING, MARCH 22, 1913.

Where Stored	Location of Root	Diameter	Length	Temperature	Results
Outside since January 12, 1913........	Top even with surface......	.65 in.....	14 in....	-9	No injury in first 2 in. below the surface of the soil. Cortex, cambium injured in next 4 in. All tissues injured in remainder.
Outside since January 12, 1913........	2 inches below low surface....	.35 in.....	12 in....	-9	Cambium and cortex injured throughout. Sap wood slightly injured in last 3 in.
Outside since January 12, 1913........	4 inches below surface....	.3 in.....	12 in....	-9	Cortex and cambium injured severely throughout. Sap wood and pith in last 8 inches.

Where Stored	Location of Root	Diameter	Length	Temperature	Results
Outside since January 12, 1913........	6 inches below surface....	.3 in......	10 in....	–9	Cambium and cortex injured throughout. Sap wood and pith in last 6 inches.
Cold storage... since January 12, 1913......	Top even with surface......	.7 in.....	11 in....	–9	Very slight injury of cambium throughout. Cortex slightly in last 2 inches.
Cold Storage since January 12, 1913.. ...	2 inches below surface......	.3 in.....	9 in....	–9	Very slight injury of cambium throughout. Cortex injured in last 3 in.
Cold storage... since January 12, 1913......	4 inches below surface....	.35 in.....	8 in....	–9	Cambium and cortex injured throughout. Pith injury last 3 inches........
Cold storage... since January 12, 1913.....	6 inches below surface....	.3 in.....	6 in....	–9	Cambium and cortex slightly injured throughout. (Injury in all cases very much less than in those kept outside).
Greenhouse since January 12, 1913......	Top even with surface......	.7 in.....	11 in....	–9	Very severe injury throughout in cambium and cortex. Pith and wood less severely injured.
Greenhouse since January 12, 1913.....	3 inches below surface......	.55 in.....	15 in....	–9	Very severe injury in all tissues
Greenhouse since January 12, 1913.....	3 inches below surface......	.5 in.....		–9	Very severe injury in all tissues.

The following table gives the results of freezing Marianna plum roots:

TABLE 33. SHOWING RELATIVE RESISTANCE TO LOW TEMPERATURE OF YEAR-OLD SEEDLING PLUM ROOTS GROWING AND IN A THOROUGHLY DORMANT CONDITION.

DATE OF FREEZING, MARCH 22, 1913.

Where Stored	Location of Root	Diameter	Length	Temperature	Results
Outside........	Top even with surface......	.8 in.....	16 in....	–9	Very slight injury of cambium in first 10 in. Cortex and cambium injured in remainder.
Outside........	3.5 inches below surface....	.3 in.....	12 in....	–9	Cambium and cortex injury throughout.
Outside........	4 inches below surface......	.3 in.....	14 in....	–9	Cambium and cortex injury throughout.
Outside........	4 inches below surface......	.25 in.....	6 in....	–9	Cambium and cortex injury throughout. Pith injured slightly in last 4 inches.
Cold storage...	Top even with surface......	.8 in. ..	9 in....	–9	Very slight injury in cambium in first 7 in. Cortex and cambium injury in remainder.
Cold Storage...	7 inches below surface......	.35 in.....	8 in....	–9	Slight injury of cambium and cortex throughout.
Cold storage...	7 inches below surface......	.35 in.....	7 in....	–9	Slight injury of cambium and cortex throughout.
Greenhouse....	Top even with surface......	.7 in......	7 in....	–9	Very severe injury of cortex and cambium throughout. Pith and sap wood injured.

Where stored	Location of Root	Diameter	Length	Temperature	Results
Greenhouse....	7 inches below surface......	.45 in.....	10 in....	–9	Very severe injury of cortex and cambium throughout. Pith and sap wood injury.
Greenhouse....	7 inches below surface......	.35 in.....	3 in....	–9	Very severe injury of all tissue.

In the root system of trees growing out of doors there is great difference in the relative hardiness. The crown of the tree—that is, the part of the root just beneath the ground—will withstand considerably lower temperatures than parts of the root lower down, and the small ends of the roots kill more easily than the larger parts. In fact as the roots extend away from the crown they become more and more tender and apparently this tenderness is greater on those roots that extend downward into the soil. Goff thinks that in Wisconsin the ends of the roots may be killed during every winter. The following table presents data covering this point. The Angers quince roots were frozen on January 25, 1913; the seedling peach roots on March 22, 1913 and the balance on March 24, 1913. See also Table 36 for the same kind of data on plum and cherry roots.

TABLE 34. SHOWING RELATIVE HARDINESS OF VARIOUS PARTS OF THE ROOT SYSTEM OF FRUIT TREES.

Kind of Root	Location of Root	Largest Diameter	Length	Temperature	Results
Two-year Kieffer pear on Japan stock........	Top even with surface......	1 in.......	16 in....	–10	No injury in first inch. Cambium injury throughout remainder. Cortex injury last 13 inches. Sap wood in last 9 in.

Kind of Root	Location of Root	Largest Diameter	Length	Temperature	Results
Two-year Kieffer pear on Japan stock........	4 inches below surface......	.5 in.....	12 in....	−10	Cambium and cortex injury throughout. Sap wood injury in last 8 inches.
Two-year Kieffer pear on Japan stock........	4 inches below surface......	.45 in....	10 in....	−10	Cambium, cortex and sap wood injured. throughout.
Two-year Kieffer pear on Japan stock........	4 inches below surface......	.3 in....	6 in....	−10	Cortex and cambium injured severely throughout; sap wood in last 5 inches.
Kieffer pear roots........	Top even with surface......	1.2 in....	15 in....	−10	No injury in first 8 inches; slight injury in cortex and cambium in remainder.
Kieffer pear roots........	4.5 in below surface......	.6 in....	12 in....	−10	No injury in first 2 inches; cambium and cortex injury in remainder; pith injury in last 5 inches.
Kieffer pear roots........	6 inches below surface......	.4 in....	12 in....	−10	No injury in first 3 inches; cambium and cortex and sap wood injury in remainder.
Kieffer pear roots........	.3 inches below surface...	.3 in....	8 in....	−10	Cambium and cortex injury throughout. Sap wood injury in last 4 inches..

Kind of Root	Location of Root	Largest Diameter	Length	Tem-pera-ture	Results
Two-year Ben Davis apple roots........	Top even with surface......	.8 in....	12 in....	-10	No injury in first 2 in. from top. Cambium injury in remainder. Cortex injury in last 3 inches.
Two-year Ben Davis apple roots........	6 inches below surface......	.25 in...	10 in....	-10	Slight injury in cambium throughout. Cortex injury in last 2 inches.
Two-year Ben Davis apple roots........	6 inches below surface......	.25 in...	8 in....	-10	Cortex and cambium injury throughout. Pith injury in last 5 inches.
Two-year Ben Davis apple roots........	6 inches below surface......	.2 in....	6 in....	-10	All tissues injured throughout.
Two-year Ben Davis apple roots........	6 inches below surface......	.2 in....	12 in....	-10	Cortex and cambium injury throughout. Sap wood injury in last 6 inches.
Two-year Ben Davis apple roots........	Top even with surface......	.8 in....	14 in....	-10	Cambium injury throughout. Cortex injury in last 6 in; sap wood in last 5 inches.
Two-year Ben Davis apple roots........	5 inches below surface......	.25 in...	8 in....	-10	Very slight injury in cortex and cambium in last 2 inches.
Two-year Ben Davis Apple roots........	9 inches below surface......	.35 in...	8 in....	-10	Cortex and cam bium injury throughout Sap wood injury in last 5 inches.

Kind of Root	Location of Root	Largest Diameter	Length	Temperature	Results
Two-year Ben Davis apple roots........	11 inches below surface....	.3 in....	6 in....	–10	Cortex and cambium injury throughout. No injury in sap wood.
One-year French apple seedlings.....		.4 in....	12 in....	–10	Cambium injury in last 11 in; cortex injury in last 6 in; pith injury in last 2 inches.
One-year French apple seedlings.....		.4 in....	11 in....	–10	Cambium injury throughout; cortex injury in last 10 in; sap wood injury in last 4 inches.
One-year French apple seedlings.....		.35 in...	8 in....	–10	Cambium slightly injured throughout; cortex injury in last 3 inches.
One-year Japan pear seedlings.....		.4 in....	11 in....	–10	Cambium injury throughout; cortex injury in last 7 inches sap wood injury in last 3 inches.
One-year Japan pear seedlings.....		.4 in....	10.5 in...	–10	Cambium injury throughout; cortex injury in last 8 inches; sap wood injury in last 2 inches.
One-year Japan pear seedlings......		.35 in...	9 in....	–10	Cambium injury throughout; cortex injury in last 7 inches; sap wood injury in last 4 inches.
Angers Quince roots........		.5 in....		–7	Cortex slightly injured.

Kind of Root	Location of Root	Largest Diameter	Length	Temperature	Results
Angers Quince roots........		.25 in...		-7	Cortex injured.
Angers Quince roots........		.18 in...		-7	Cortex and cambium injured.
Angers Quince roots........		.12 in...		-7	Cortex and cambium injured.
Angers Quince roots........		.5 in....		-9	Cortex injured.
Angers Quince roots........		.25 in...		-9	Cortex injured.
Angers Quince root.........		.18 in...		-9	Cortex and cambium injured.
Angers Quince roots........		.12 in...		-9	Cortex and cambium injured.
Seedling Peach roots........	Top even with surface......	.65 in...	14 in....	-9	No injury in first 2 inches from top; cortex and cambium slightly injured in next 4 in; all tissues injured in remainder.
Seedling Peach roots........	2 inches below surface......	.35 in...	12 in....	-9	Cambium and cortex injury throughout. Sap wood slightly injured in last 3 inches. Injury very slight nearest crown.
Seedling Peach roots........	4 inches below surface......	.3 in....	12 in....	-9	Cambium and cortex injured severely throughout. Sap wood and pith injury in last 8 in.
Seedling Peach roots........	6 inches below surface......	.3 in....	10 in....	-9	Cambium and cortex injury throughout. Sap wood and pith injury in last 6 inches.

Four-year old Elberta peach roots subjected on October 19, 1911, to a temperature of -4° C., showed both live and dead tissue intermingled. The younger roots lying some distance from the trunk of the tree showed the tissue to be all dead, killing worse than the larger roots near the trunk.

These roots were in all cases kept during the time preceding the freezing in such a position that all parts must have been exposed to practically the same temperature, so it is not possible that the diminished hardiness of the parts furthest from the crown could have been caused by their being exposed to a higher temperature during the period preceding the freezing. It probably represents the most rapidly growing tissue, but at times of freezing the tissue had not been growing for at least three months. It also represents tissue that under normal conditions is not so liable to be exposed to low temperatures so in the evolution of the plant it would not be so necessary for it to develop hardiness.

Of great interest, practically, is the hardiness of various stocks of fruit trees. Through the courtesy of Mr. E. S. Welch of Shenandoah, Iowa, this station was able to study various stocks. In the case of apple trees worked on French crabs, a considerable number of trees were furnished that had rooted from the scions, as well as from the stock, thus permitting a comparison between these scion roots and the roots from the stock. The trees were received December 20, 1912 and were heeled-in in the shade. The roots were thus at a temperature near the freezing point from the time they were received until they were frozen. The following table gives the results:

TABLE 35. SHOWING RELATIVE HARDINESS OF STOCK AND SCION ROOTS.

Date of Freezing	Temperature	Material and Results
		Two-year old Ben Davis apple trees.
Feb. 18,'13	−11	Scion root diameter 3/16 in. uninjured for first 6 inches. Cortex and cambium injury in remainder.
Feb. 18,'13	−11	Similar root from stock dia. 3/16 in., uninjured for first 7 inches. Cortex and cambium injury in remainder.
Feb. 20,'13	−15	A. Scion root, largest dia. 3/8 in., length 14 in. No injury whatever.
Feb. 20,'13	−15	B. Scion root, coming from scion 2 inches below A. Largest dia. 1/8 in; length 12 in. No injury in first 5 inches; last 7 inches were slightly browned.
Feb. 20,'13	−15	C. Scion root, 2 inches lower than B. Largest dia. 5/16 in; length 12 in. No injury in first 6 inches; slight injury in last 6 inches.
Feb. 20,'13	−15	D. Stock root, 1 inch below C. Largest dia. 3/8 in; length 10 in. Severe injury throughout.
Feb. 20,'13	−15	E. Stock root, 2 inches below D. Largest dia. 1/2 in; length 10 in. Very severely injured throughout.
Feb. 20,'13	−15	F. Stock root, 1/4 inch below E. Largest dia. 3/8 in; length 12 inches. Severe injury throughout.
Feb. 20,'13	−15	G. and H. Arise at same point as F. Each 1/4 in. in dia. at largest point; both 12 in. long. Severe injury in both.
Feb. 20,'13	−15	Main root. Largest dia. 3/4 in. No injury to scion part. Injury to cortex in stock part.
Feb. 20,'13	−15	Fibrous roots under 1/16 in. dia. Injury on those from stock and not on those from scion.
Mar. 3,'13	−15	A. Scion root 4 inches below ground. Largest dia. 1/2 in; length 10 in. No injury in first 5 inches. Remainder very slightly browned.
Mar. 3,'13	−15	B. Stock root attached 2 inches below A. Largest dia. 1/4 in; length 14 in. Injury throughout entire length.
Mar. 3,'13	−15	C. Stock root 2 inches below B. Largest dia. 1/2 in; length 10.in . Injury in first 4 inches slight; remainder well browned.
Mar. 3,'13	−15	D. Stock root same size as C. Attached at same portion of main root. Injury somewhat more severe than C.
Mar. 3,'13	−15	Main root. Scion part, dia. 3/4 in., shows no browning. Stock part, dia. 1/2 in. is slightly browned.
		Two-year old Wealthy apple trees
Mar. 3,'13	−15	A. Scion root. Largest dia. 1/2 in; length 12 in. No injury in first 7 inches; remainder slightly injured.
Mar. 3,'13	−15	B. Continuation of main root. Largest dia. 3-8 in; length 8 in. No injury in first 3 inches; last 5 inches slightly injured.
Mar. 3,'13	−15	C. Stock root. Largest dia. 1/2 in; length 12 in. Arises nearly opposite Root A. No injury in first 6 inches; remainder slightly injured. No marked difference between A and B.

In most cases those roots that came from scions were more hardy than those of the same size coming from the stock, indicating that the French seedling roots are less hardy than roots of a variety like Ben Davis. This station has been unable to compare the hardiness of scion roots from hardy varieties like Fameuse with those from very tender varieties like Jonathan.

A comparison similar to the foregoing was made with different stock of plums and cherries using the Myrobolan and Marianna varieties of plums and Mazzard and Mahaleb varieties of cherries. The following table gives the results:

TABLE 36. SHOWING RELATIVE HARDINESS OF MAZZARD AND MAHALEB CHERRY STOCK AND MARIANNA AND MYROBOLAN PLUM STOCK.

Date of Freezing, January 25, 1913.

Kind of Root	Location of Root	Largest Diameter	Length	Temperature	Results
Mazzard cherry roots..		½ in......		–7	No injury.
Mazzard cherry roots..		¼ in......		–7	No injury.
Mazzard cherry roots..		3/16 in......		–7	No injury.
Mazzard cherry roots..		⅛ in......		–7	Slight injury in cortex.
Mazzard cherry roots..		½ in......		–9	No injury.
Mazzard cherry roots..		¼ in......		–9	No injury.
Mazzard cherry roots..		3/16 in......		–9	Slight browning in cortex.
Mazzard cherry roots..		⅛ in......		–9	Cortex and cambium injured.
Mahaleb cherry roots..		½ in......		–7	No injury.
Mahaleb cherry roots..		¼ in......		–7	No injury.
Mahaleb cherry roots..		3/16 in......		–7	Cortex injured.
Mahaleb cherry roots..		⅛ in......		–7	Cortex injured.
Mahaleb cherry roots..		½ in......		–9	Cortex injured.
Mahaleb cherry roots..		¼ in......		–9	Cortex and cambium injured.
Mahaleb cherry roots..		3/16 in......		–9	Cortex and cambium injured.
Mahaleb cherry roots..		⅛ in......		–9	Cortex and cambium injured.

Date of Freezing, March 18, 1913.

Kind of Root	Location of Root	Largest Diameter	Length	Temperature	Results
Mazzard cherry roots..	3 inches below surface......	1.1 in....	7 in....	−10	Cambium and cortex injured throughout. Least severe near crown.
Mazzard cherry roots..	3.5 inches below surface...	.3 in....	5 in....	−10	Cambium and cortex injured throughout. Least severe near crown.
Mazzard cherry roots..	4 inches below surface......	.3 in....	7 in....	−10	Cambium and cortex injured throughout. More severe than above.
Mazzard cherry roots..	4.5 inches below surface....	.3 in....	12 in....	−10	Cambium and cortex injured severely throughout
Mazzard cherry roots..	5 inches below surface......	.45 in...	6 in....	−10	Very severe injury in cambium and cortex throughout.
Mazzard cherry roots..	5.5 inches below surface....	.4 in....	10 in....	−10	Very severe injury in cambium and cortex throughout.
Mazzard cherry roots..	5¾ inches below surface....	.28 in...	28 in....	−10	Cortex and cambium injured severely. Pith injured slightly.
Mazzard cherry roots..	6¼ in. below surface......	.15 in...	8 in....	−10	All regions injured.
Mazzard cherry roots..	6¾ inches below surface....	2 in......	6 in....	−10	All regions injured.
Mazzard cherry roots..	9¼ in. below surface.......	1 in......		−10	All regions injured.

Kind of Root	Location of Root	Largest Diameter	Length	Temperature	Results
Mazzard cherry roots..	2 inches below surface.......	1 in......	8 in....	−10	Cortex and cambium injury throughout. Least injury near crown. Pith killed last 5 inches.
Mazzard cherry roots..	3 inches below surface......	.3 in....	6 in....	−10	All tissues severely injured.
Mazzard cherry roots..	4 inches below surface......	.3 in....	10 in....	−10	Cambium and cortex injured severely first 3 inches of root. All tissues injured in remainder.
Mazzard cherry roots..	4 inches below surface......	.5 in....	10 in....	−10	Cambium and cortex injury throughout. Pith injury last 5 inches.
Mazzard cherry roots..	4½ inches below surface....	.45 in...	14 in....	−10	Cambium and cortex injured very severely throughout. Pith injured in last 12 inches.
Mazzard cherry roots..	6½ inches below surface....	.4 in....	8 in....	−10	Cambium and cortex injured very severely throughout. Pith injured in last 3 inches.
Mazzard cherry roots..	7½ inches below surface..	.2 in....	6 in....	−10	All tissues injured throughout.
Mazzard cherry roots..	9 inches below surface......	.15 in...	6 in....	−10	All tissues injured throughout.
Mazzard cherry roots..	10½ inches below surface....	.2 in....	4-6 in..	−10	All tissues very severely injured.
Mazzard cherry roots..	6 inches below surface......	.15 in...	3 in....	−10	All tissues very severely injured.

Kind of Root	Location of Root	Largest Diameter	Length	Temperature	Results
Mahaleb cherry roots..	2 inches below surface.......	1 in......	13 in....	−10	No injury in first 6 in. Very slight injury in cambium in next 3 in. Cambium and cortex injury in remainder.
Mahaleb cherry roots..	8 inches below surface......	.2 in....	4 in....	−10	Cambium and cortex injury throughout.
Mahaleb cherry roots..	10 inches below surface....	.35 in...	4 in....	−10	Cambium and cortex very slightly injured.
Mahaleb cherry roots..	6 inches below surface......	.1 in....	4 in....	−10	Cambium and cortex injured severely.
Mahaleb cherry roots..	2 inches below surface....	1 in......	14 in....	−10	No injury in first 4 inches. Cambium and cortex injured very slightly throughout remainder.
Mahaleb cherry roots..	6 inches below surface......	.4 in....	6 in....	−10	Cambium and cortex injury throughout.
Mahaleb cherry roots..	10 inches below surface....	.35 in...	2 in....	−10	Slight injury in cambium and cortex.
Mahaleb cherry roots..	9½ inches below surface....	.2 in....	3 in....	−10	Cambium and cortex injured.
	Date of Freezing, March 21, 1913.				
Mazzard cherry roots..	At surface....	1.1 in....	11 in....	−10	Cambium injured throughout. Cortex injury in last 8 in. More severe near terminal; least injury near crown.

Kind of Root	Location of Root	Largest Diameter	Length	Temperature	Results
Mazzard cherry roots..	3 inches below surface......	.45 in...	8 in....	–10	Cambium injured throughout. Cortex injured in last 5 in. Least injury nearest crown.
Mazzard cherry roots..	3 inches below surface......	.3 in....	4 in....	–10	Cambium slightly injured throughout.
Mazzard cherry roots..	3½ inches below surface....	.4 in....	6 in....	–10	Cambium and cortex injury very slight.
Mazzard cherry roots..	5 inches below surface......	.3 in....	10 in....	–10	Cambium and cortex injured throughout. Pith injured in last 3 inches.
Mazzard cherry roots..	10 inches below surface....	.3 in....	8 in....	–10	Cambium and cortex severely injured throughout. Pith injured less severely.
Mazzard cherry roots..	At surface....	1.1 in....	13 in....	–10	Cambium injury throughout. Cortex and cambium in last 8 in. Cortex, cambium and pith in last 5 inches.
Mazzard cherry roots..	2 inches below surface......	.5 in....	10 in....	–10	Cambium injury throughout. Cortex and cambium in last 8 in. Cortex, cambium and pith in last 5 inches.
Mazzard cherry roots..	2 inches below surface.......	.45 in...	8 in....	–10	Cortex and cambium injury throughout.
Mazzard cherry roots..	2½ inches below surface....	.5 in....	5 in.....	–10	Cortex and cambium injury throughout.

Kind of Root	Location of Root	Largest Diameter	Length	Temperature	Results
Mazzard cherry roots..	3 inches below surface......	.3 in....	5 in....	–10	Cortex and cambium severely injured throughout. Pith injury in last 4 in.
Mazzard cherry roots..	7 inches below surface......	.25 in...	5 in....	–10	Cortex and cambium injury throughout. Pith injury in last 3 inches.
	Date of Freezing, March 21, 1913.				
Mahaleb cherry roots..	1 inch below surface....	1 in......	10 in....	–10	No injury in 5 in. nearest crown. Cortex injury slight in remainder.
Mahaleb cherry roots..	2 inches below surface......	.15 in...	6 in....	–10	Cambium slightly injured in first 2 in. Cambium and cortex in remainder.
Mahaleb cherry roots..	3 inches below surface......	.4 in....	8 in....	–10	Cambium and cortex injury throughout. Very slight nearest crown. Pith injury in last 2 inches.
Mahaleb cherry roots..	4 inches below surface......	.4 in....	6 in....	–10	Cambium and cortex injury slight in first 2 in.; more severe in next 2 in. Cambium, cortex and pith injury in terminal 2 inches.
Mahaleb cherry roots..	5 inches below surface......	.3 in....	4 in....	–10	Cambium and cortex slightly injured.
Mahaleb cherry roots..	1 inch below surface......	1 in......	14 in....	–10	No injury in highest 7 in. Very slight injury in cambium and cortex of remainder.

Kind of Root	Location of Root	Largest Diameter	Length	Temperature	Results
Mahaleb cherry roots..	4 inches below surface......	.3 in....	8 in....	–10	No injury in first 4 in.; slight injury in cambium and cortex in remainder.
Mahaleb cherry roots..	4 inches below surface......	.45 in...	10 in....	–10	No injury in first 3 inches; cambium and cortex injury in remainder; injury becoming more severe near terminal.
Mahaleb cherry roots..	4 inches below surface......	.5 in....	5 in....	–10	No injury first inch. Cambium and cortex injured in remainder.
Mahaleb cherry roots..	7 inches below surface......	.3 in....	3 in....	–10	Slight injury in cambium and cortex.
	Date of Freezing, March 18, 1913.				
Myrobolan plum roots....	2 inches below surface......	.8 in....	7.5 in	–10	Cortex injured first 5 in.; cortex and cambium injured next 2½ inches.
Myrobolan plum roots...	3 inches below surface......	.4 in....	9.5 in.	–10	Cortex and cambium injured in all. Pith injured in last 5½ inches.
Myrobolan plum roots...	6 inches below surface......	.2 in....	6 in....	–10	All regions injured, less severe near point of attachment.
Myrobolan plum roots...	9 inches below surface......	.3 in....	3 in....	–10	All regions injured, less severely near point of attachment.
Myrobolan plum roots...	12 inches below surface..	.25 in...	3 in....	–10	All regions very severely injured.

Kind of Root	Location of Root	Largest Diameter	Length	Temperature	Results
Myrobolan plum roots...	14 inches below surface....	1 in......	6 in....	−10	All regions very severely injured.
Myrobolan plum roots...	2 inches below surface......	.7 in....	12 in....	−10	Cortex injured slightly in first 3 in.; cortex and cambium injured slightly next 6 in.; pith injured slightly and cortex and cambium severely in last 3 inches.
Myrobolan plum roots...	2¾ inches below surface....	.3 in....	6 in....	−10	Cortex injury in first inch. Cortex and cambium injury in remainder, severe near terminal.
Myrobolan plum roots...	3¼ inches below surface....	.2 in....	8 in...	−10	All tissues injured. Injury most severe near terminal.
Myrobolan plum roots...	4¼ inches below surface....	.3 in....	10 in...	−10	All tissues injured. Injury most severe near terminal.
Myrobolan plum roots...	4¾ inches below surface....	.2 in....	9 in....	−10	Same as above.
Myrobolan plum roots...	11 inches below surface....	.35 in...	3 in....	−10	Same as above.
Myrobolan plum roots...	11 inches below surface	.15 in...	3 in....	−10	Same as above.
	Date of Freezing, March 20, 1913.				
Marianna plum roots...	7 inches below surface......	1 in......	2 in....	−10	No injury noticeable.
Marianna plum roots...	9 inches below surface......	.6 in....	12 in....	−10	Slight injury to cambium in first 6 inches; all tissue injured in remainder.

Kind of Root	Location of Root	Largest Diameter	Length	Temperature	Results
Marianna plum roots...	9 inches below surface......	.55 in...	6 in....	−10	Cambium injured first 3 inches. Cambium and cortex in remainder.
Marianna plum roots...	9 inches below surface......	.5 in....	12 in....	−10	Cambium injured first 3 inches. Cortex and cambium next 2 inches; cortex, cambium and pith in remainder.
Marianna plum roots...	9 inches below surface......	.5 in....	5 in....	−10	Cambium and cortex injured very slightly throughout.
Marianna plum roots...	9 inches below surface......	.45 in...	10 in....	−10	All tissues injured.
Marianna plum roots...	12 inches below surface....	.2 in....	6 in....	−10	All tissues injured.
Marianna plum roots...	9 inches below surface.......	.4 in....	10 in....	−10	All tissues injured.
	Date of Freezing, March 24, 1913.				
Marianna plum roots...	1 inch below surface......	1 in......	14 in....	−10	No injury to first 5 inches; slight injury to cambium next 3 inches; slight injury to cortex in remainder.
Marianna plum roots...	2 inches below surface......	.4 in....	8 in....	−10	Slight injury in cortex and and cambium throughout. More severe towards tip.
Marianna plum roots...	2½ inches below surface....	.3 in....	10 in....	−10	Same as above.
Marianna plum roots...	2 inches below surface......	.2 in	8 in....	−10	Same as above.
Marianna plum roots....	6 inches below surface......	.35 in...	14 in....	−10	Cambium and cortex injured throughout. More severe last 8 in. Pith last 4 in.

Kind of Root	Location of Root	Largest Diameter	Length	Temperature	Results
Marianna plum roots...	6½ inches below surface....	.15 in...	6 in....	−10	Cambium and cortex injured throughout.
Marianna plum roots...	8½ inches below surface....	.15 in...	4 in....	−10	Cambium and cortex injured throughout.
Marianna plum roots...	10½ inches below surface....	.45 in...	3 in....	−10	Cambium and cortex slightly injured.
Myrobolan plum roots...	1 inch below surface......	.8 in....	12 in...	−10	Cortex, cambium and pith injured slightly throughout. More severe further from crown.
Myrobolan plum roots...	3 inches below surface......	.3 in....	10 in....	−10	Cambium and cortex injured severely throughout; pith injured slightly.
Myrobolan plum roots...	4½ inches below surface....	.3 in....	8 in....	−10	Same as above.
Myrobolan plum roots...	5 inches below surface......	.25 in...	9 in....	−10	All tissues severely injured.
Myrobolan plum roots...	At surface....	.8 in....	10 in....	−10	Cambium, cortex and pith injured in all. More severely near tip.
Myrobolan plum roots...	3 inches below surface......	.35 in...	8 in....	−10	Cambium and cortex severely injured throughout. Pith injured in last 5 inches.
Myrobolan plum roots...	5 inches below surface.......	.2 in....	4 in....	−10	Cambium and cortex severely injured throughout. Pith injured slightly.
Myrobolan plum roots...	7 inches below surface......	.2 in....	4 in....	−10	All tissues severely injured.

Freezing to Death of Pollen. The killing of the bloom and young fruit of the peach, apple and some other fruits will be discussed later in this paper. However, it is perhaps not out of place to discuss here the killing of pollen. Schaffnit[1] exposed the pollen of a number of species of plants to a temperature of -17° C. for eight hours with no apparent harmful effects, while Sandsten[2] apparently reduced the germination percentage of pear, plum, cherry and peach pollen by exposing for six hours to a temperature of 1.5°. At this station pollen of the Jonathan and Cillago apples was frozen with the result shown in Table 37. The pollen was frozen for eighteen hours and then germinated in a 10% sugar solution.

TABLE 37. SHOWING EFFECT OF LOW TEMPERATURE ON GERMINATING POWER OF POLLEN GRAINS.

Kind of Pollen	Date	Temperature	Time at Minimum	Percentage Germination Unfrozen	Percentage Germination Frozen
Jonathan apple.......	Apr. 24,'13	-3	45 min....	84.0	33.0
Jonathan apple....... pollen dried.......	May 29,'13	-13	60 min....	25.0 (estimate)	20.0 (estimate)
Cillago apple.........	May 10,'13	-8	30 min....	66.66	25.0
Cillago apple.........	May 10,'13	-12.5	30 min....	66.66	00.0

Thus the pollen will still germinate after exposure to as low temperature as -8° C., and dried pollen at as low a temperature as -13, a much lower temperature than the other flower parts will withstand.

Discussion of the killing temperature of other flower tissues will be found in a later part of this paper.

Rest Period of Plants. Closely associated with the question of maturity in the fall is that of maintaining a condition of maturity in late winter. Plants that have started into growth in spring soon reach a condition whereby they are as tender as they were in early fall, and sometimes even more so. Under conditions such as prevail in the southern half of Missouri, where growth may continue late in autumn, and where in January and early February, there are likely to be days warm enough for considerable growth to take place, it has

[1]Mitt. Kaiser Wilhelm Inst. Landw. Bromberg. Vol. 3, No. 2, pp. 93-115, 1910. (Bibl. No. 98).

[2]Wis. Agr. Exp. Sta. Research Bul. 4, pp. 163-5. (Bibl. No. 97).

been found that with the peach, the winter rest period of the fruit buds is an important factor in influencing the amount of killing from cold. By the rest period is meant the period during which the buds will not respond in growth to favorable temperature conditions without special treatment. This rest period is shorter with some varieties than with others, and with all varieties tried at this station the rest period is prolonged later into the winter if the tree makes a vigorous growth and continues growing rather late in the season. They will not, therefore, respond so readily to warm periods that may come in late December or January.

Winter Protection of Buds. The buds of trees in winter are covered with bud scales. Some hold that the insulation formed by these scales will keep the buds from reaching a temperature as low as that of the surrounding air. Wiegand[1] however, found that when a thermometer bulb was carefully inserted in large buds there was no great difference between the rapidity of the fall of temperature on such a thermometer and one with a naked bulb. He, therefore, holds that the bud scales offer little protection in the way of holding heat in the buds, but that their protection is against evaporation. To test this matter at this station the scales were removed from buds of peaches in winter before freezing in the freezer previously described with the results shown in Table 38.

[1]Bot. Gaz. Vol. 41, pp. 373-424. (Bibl. No. 117).

TABLE 38. SHOWING EFFECT OF REMOVING SCALES FROM THE BUDS BEFORE FREEZING ON THEIR RESISTANCE TO VERY LOW TEMPERATURE.

Variety	Date of Freezing	Temperature	Number of Buds. Scales Off	Number of Buds. Scales On	Percentage Killed. Scales Off	Percentage Killed. Scales On
Elberta	Nov. 12,'09	-15	149	65	2.6	1.5
Elberta	Nov. 12,'09	-15	96	133	2.0	1.5
Elberta	Feb. 23,'10	-18	117	168	47.8	63.6
Elberta, wilted	Dec. 15,'10	-20.2	79	83	59.	81.
Elberta water-soaked	Dec. 15,'10	-15	39	35	64.	71.
Elberta, normally turgid	Dec. 15,'10	-15	89	74	46.	75.
Elberta, wilted	Dec. 23,'10	-21.5	59	57	45.	100.
Elberta, normally turgid	Dec. 23,'10	-16	56	59	55.	76.
Elberta, wilted	Dec. 24,'10	-20.5	70	79	74.	100.
Elberta, normally turgid	Dec. 24,'10	-20.5	75	75	52.	32.
Elberta, water-soaked	Dec. 27,'10	-19.7	60	77	93.	19.
Elberta, normally turgid	Dec. 27,'10	-19.7	57	48	57.	75.
Elberta, water-soaked	Dec. 28,'10	-20.5	69	72	94.	45.
Elberta, normally turgid	Dec. 28,'10	-20.5	54	56	79.	71.
Oldmixon	Nov. 26,'09	-16	100	87	29.	74.7
Oldmixon	Nov. 26,'09	-16	98	83	18.4	73.5
Oldmixon	Nov. 26,'09	-21	80	137	6.2	13.8
Oldmixon	Nov. 26,'09	-21	79	92	2.5	17.4
Oldmixon	Nov. 26,'09	-14	150	151	14.6	62.2
Oldmixon	Nov. 26,'09	-14	86	96	17.4	47.9
Oldmixon	Nov. 26,'09	-21	144	198	81.2	98.9
Oldmixon	Nov. 26,'09	-21	74	76	64.8	96.
Oldmixon	Dec. 6,'09	-22.5	196	132	15.7	54.5
Oldmixon	Dec. 6,'09	-18.5	50	290	40.	93.1
Oldmixon	Jan. 14,'10	-21	185	223	96.6	99.5
Oldmixon	Jan. 15,'10	-21	218	262	75.6	97.7
Oldmixon	Mar. 23,'10	-10	156	140	57.	57.1
Bell's Oct., slowly	Feb. 7,'10	-20	210	107	33.8	83.1
Bell's Oct.	Feb. 8,'10	-20.5	298	239	46.6	63.6
Bell's Oct.	Feb. 15,'10	-20	267	353	100.	97.4
Bell's Oct., rapidly	Feb. 16,'10	-20.5	200	249	100.	100.
Bell's Oct.	Feb. 17,'10	-20	180	200	100.	98.
Bell's Oct., slowly	Feb. 18,'10	-18	121	195	17.3	40.5
Bell's Oct., rapidly	Feb. 19,'10	-18	76	245	82.9	93.0
Bell's Oct.	Dec. 6,'10	-21	69	100	66.	45.
General Lee, slowly	Feb. 26,'10	-20.3	233	220	8.5	13.8
General Lee	Feb. 26,'10	-21	71	111	11.2	19.8
Total number of buds			4430	5078		
Average percentage killed			....	....	51.0	68.5

It will be seen that not only in this case were the scales no protection against the cold, but in actual fact those buds that had the scales removed had very uniformly a smaller percentage killed than those still protected by the bud scales. This is at least true during the most dormant condition in winter. Toward spring when the buds have swelled considerably, during warm days, there seems to be practically no difference between the percentage killed with the scales removed and those with the scales on. This seems to demonstrate conclusively that, at least in the case of peaches, the bud scales do not serve to protect the bud from cold, but as Wiegand points out, the bud scales serve only to protect the bud from loss of water by evaporation.

RELATION OF LOW TEMPERATURE TO PEACH GROWING.

Peach Wood Killing. As mentioned previously, on some years the peach wood is badly injured. Generally this injury follows very severe cold winters with lower temperatures than are necessary to kill the buds. However, on some years the wood has been reported badly injured even when a fair set of bloom followed. It is difficult to say just what weather conditions favor winter killing of peach wood in all cases. In the case of young trees, one to three years old, Emerson[1] found that in Nebraska they are more likely to survive the average winter if forced to mature their wood early in autumn, by using gross feeding cover crops as previously mentioned, though older trees were not benefited by such a practice. Eustace[2] reports that following the severe winter of 1903-04 in New York, peach trees more than seven years of age were killed worse than peach trees about seven years of age or younger, except trees one year in the orchard which killed the worst. Green[3] and Ballou, following the same winter, observed that old trees were killed worse than young trees and that trees kept in a good condition of vigor by use of stable manure, mulch, etc., were in better condition than trees that had been permitted to become weak in their growth. This may have been partly because of the dry weather in early summer followed by wet weather in late summer and autumn. The old trees would have been checked in growth more by the drought and thrown into more succulent growth by the later rains, while the more vigorous young trees would be better able to secure sufficient water and tend to continue

[1]Neb. Agr. Exp. Sta. Bul. 79, 1903. (Bibl. No. 33).
[2]N. Y. (Geneva) Exp. Sta. Bul. 269, 1905. (Bibl. No. 38).
[3]Ohio Agr. Exp. Sta. Bul. 157, 1894. (Bibl. No. 48).

their growth through the drought, and be just starting into their normal dormant period when the wet weather began. They would, not therefore, be so easily pushed into new growth as if they had passed through a drying out period. At least observation indicates that the weak tree which ceases growth early in the season is most readily pushed into spring-like growth in autumn.

It is probably also true that the young tree would offer less resistance to the movement of sap upward in spring. It would thus be able to secure sufficient water supply to prevent drying out until a new layer of sapwood is formed. The old tree would have a greater leaf surface to evaporate moisture and would offer more resistance to the movement of sap. It would, therefore, seem possible that the young tree might recover from the freeze better, though its injury had been greater than that of the older tree.

In the peach orchards on the Horticultural grounds and at Brandsville and other points in South Missouri, following the severe winter of 1904-05 and again following the severe winter of 1911-12, the trees in a healthy, vigorous condition withstood the low temperature better than trees in a weak condition of growth. At Brandsville and other extreme southern Missouri points, following the freeze of 1911-12, recovery was much more satisfactory from trees that had been fertilized with nitrate of soda than with trees that had not been so fertilized. This was even true with one year old trees which is contrary to the experience of Emerson,[1] but it should be noted that the soil is more conducive to early maturity and the growing season longer in southern Missouri than in Nebraska.

As to the best means of securing recovery of trees from winter injury, a great deal depends upon the nature of the injury. Thus following the winter of 1899, Whitten[2] reports that trees very severely pruned, leaving the branches only a few feet long, recovered much better than trees not headed so severely. Following the severe winter of 1904-05 trees rather severely headed-in recovered better than trees that had only one-third or one-half of the previous season's wood cut off. However, Eustace[3] found that this severe heading back of the trees in New York, following the winter of 1903-04, was very harmful to old trees, though apparently beneficial to young trees. Moderate pruning gave much better results.

[1]Neb. Agr. Exp. Sta. Bul. 79, 1903; (Bibl. No. 33) and Neb. Agr. Exp. Sta. Anl. Rpt. No. 19, 1906, pp. 101-10 (Bibl. No. 35).

[2]Mo. Agr. Exp. Sta. Bul. 55, 1902. (Bibl. No. 115).

[3]N. Y. (Geneva) Exp. Sta. Bul. 269, 1905. (Bibl. No. 38).

Waite[1] reports that very severe pruning of trees in Michigan and other parts of the North, following the same winter, did not give as good results as light pruning—removing about one-third to one-half of the one year old wood,—and in Missouri, both in the Experiment Station orchard and in orchards at Brandsville and Hollister of southern Missouri, old trees that were severely cut back following the severe winter of 1911-12 did not recover as well as old trees with even no cutting back. The amount of cutting that seemed to have been the most desirable, following either the winter of 1908-09 or 1904-05, in Missouri, was in a large number of cases fatal in 1911-12. At Brandsville a large block of trees that had reached a height of something like fifteen feet had their branches cut back to stubs four or five feet long, and a large percentage of the trees died, after making some slight growth in the spring, while trees with no pruning or very light pruning recovered much better.

Just what the difference is it is hard to say, except that preceding the winter of 1911-12, growth conditions were much the same as those described by Waite, Selby and Eustace for Michigan, Ohio and New York preceding the winter of 1903-04; that is, dry weather in the early part of the season, followed by very wet weather causing a late succulent growth.

In deciding how much pruning to give a tree following a severe winter, one must consider the kind of injury. If the lower part of the tree is very severely injured, as it will be when the tree is forced into late succulent growth following conditions that seriously check its growth earlier, the pruning should probably be such as to remove not more than one-half of the one-year-old wood, while if the injury is distributed throughout the tree, and is not so severe that the cortex and cambium are entirely killed at any point, it would seem highly probable that more severe cutting back—say into two-year-old wood—would be desirable. Such cutting back is often beneficial to the trees even when they do not need it to help them recover from severe freezes. However, very severe cutting back, such as Whitten describes, is probably not the most desirable following any kind of a winter since much less cutting will give entirely satisfactory results and a better tree with more fruit buds for the following season's crop. Cutting back to induce recovery from winter injury has always been more successful at this station on young trees than on old ones and on trees kept vigorous by severe pruning during previous years than on less vigorous trees. In fact if trees are old and neglected, severe cutting back all in one year should always be avoided.

[1]U. S. Dept. Agr. B. P. I. Bul. 51, pp. 15-19. (Bibl. No. 111).

Eustace reports that trees pruned in January, shortly after a severe freeze, gave much better results than trees pruned in March, probably because a large amount of drying out had been avoided by reducing the top. At this station better results have been secured by the early pruning. Fertilizing the soil with a nitrogenous fertilizer, as nitrate of soda or ammonium sulphate, has, at Brandsville, Missouri, resulted in much more satisfactory recovery from winter injury. Where the fertilizer was applied both the year before and the year following the freeze, very slight permanent injury was to be found when surrounding unfertilized trees suffered great injury.

Hardiest Varieties in Wood. The effect of the condition of growth on the hardiness of peach wood is so great that it is difficult to reach an accurate conclusion as to which are the hardiest varieties. Observations must be on a large number of trees, and through a large enough number of years to include many different seasonal conditions. Hedrick,[1] basing his opinion on replies secured from New York growers, places Crosby, Hills Chili, Stevens Rareripe, Gold Drop and Elberta as most hardy in wood; and from replies from Michigan growers, Hills Chili, Crosby, Gold Drop, Kalamazoo, and Bernard. Elberta, Smock and Salway, considered hardy in New York, were considered tender in Michigan. Wager, Jaques Rareripe, Carman, Belle of Georgia, and Hale's Early were considered above the average in hardiness. Eustace[2] found in New York, following the winter of 1903-04, that Stevens Rareripe, Elberta, Thurber and Salway showed little or no wood injury, while Chinese Cling was the most seriously injured. R. F. Howard, formerly of the Nebraska Experiment Station, states in a letter that Russell[3] is one of the most hardy in wood.

At the Missouri Experiment Station there is a peach orchard that has been exposed to the severe winters of 1898-99, 1904-05 and 1911-12. These trees have had such different treatment that they necessarily went into winter in conditions not equally favorable to withstanding the low temperature. We are, therefore, not able to place the varieties as to hardiness with any degree of accuracy. However, it can be said with certainty that, although Elberta is very tender in bud, its wood is exceeded in its ability to recover from such winters by very few varieties. At least this is true of any but one- or two-year-old trees. Hills Chili, Salway, Bernard and Gold Drop have also proved hardy. Chinese Cling has been probably most

[1]Procs. Western N. Y. Hort. Soc. 1908, p. 180. (Bibl. No. 55).
[2]N. Y. (Geneva) Exp. Sta. Bul. 269, 1905. (Bibl. No. 38).
[3]Yearbook, U. S. Dept. Agr. 1911, p. 429. (Bibl. No. 109).

tender in wood, although it is rather hardy in bud. The station orchard contains no old trees of the Greensboro or Belle of Georgia varieties but young trees of these varieties, and of Victor and Russell, were among those that recovered best from the effects of the winter of 1911-12.

It is interesting to note that Elberta, Greensboro, Belle of Georgia, Victor and Carman are among the more hardy varieties in wood, and are seedlings of the Chinese Cling, which is one of the few most tender varieties in wood.

Killing Peach Buds. In the case of fully dormant peach buds there is but little difference in the killing temperature of the different parts of the flower. In practically all cases where there is killing at all, all of the flower parts are killed and, in addition to this, generally some of the vascular tissue extending down into the twigs from the base of the buds. This was brought out by careful sectioning of killed buds by Mr. R. G. Briggs.[1] Just how much cold a fully dormant peach fruit bud will withstand, it seems practically impossible to approximate. According to Eustace,[2] the minimum temperature that prevailed in Western New York in the winter of 1903-04 ranged from -10° F. to -15° F. In most orchards of that section there was a normal crop although the wood was badly injured, indicating that under some conditions the bud will actually withstand a lower temperature than will some of the woody tissues.

In a letter from Professor F. A. Waugh, he says that in Massachusetts practically a full crop of peaches has been harvested from trees that had been through a temperature of -20° F. and a partial crop of Greensboro had been secured following a minimum temperature of about -27° F. In a letter from Mr. Elmer B. Parker of Wilton New Hampshire, he states that after a temperature of -14° F. in January, a sudden drop, the Elberta crop was a practical failure while Carman had 50 to 75 per cent of a full crop, and Belle of Georgia and Champion had practically a full crop; and in 1910-11 a temperature of -12° F. in December failed to kill enough buds to prevent trees from yielding a full crop. In these cases the buds had not been started into growth by warm periods.

In the year of 1901-02 all of the buds were killed at the Missouri Experiment Station orchard by a temperature of -23° F. on December 20th. In 1902-03 practically all buds were killed by a temperature of -15° F. on February 17. In 1903-04 buds were killed on all varieties except General Lee, Chinese Cling, Thurber, Carman, Gold

[1]Thesis, University of Missouri, 1912. (Bibl. No. 13).
[2]New York (Geneva) Exp. Sta. Bul. 269, 1905. (Bibl. No. 38).

Drop, Triumph and Lewis, by a temperature of-14° F. on January 29. During the winter of 1904-05 nearly all the buds were killed, yet practically all trees had a few left alive and Triumph and Lewis a fair crop, following a temperature of -25° F. on February 13th. The following table gives the percentage of buds killed for a number of varieties during the season of 1905-06 and the seasons following up to 1911-12 when all were killed by a temperature of -20° F. During 1912-13 there was no severely cold weather and practically none of the buds were killed.

TABLE 39. SHOWING THE PERCENTAGE OF BUDS KILLED ON THE YEARS 1906 TO 1911 INCLUSIVE.

February 5, 1906. Temperature –3° F.

Variety	Number Buds Counted	Percentage Buds Killed
Lewis	1347	25.9
Chinese Cling	599	30.7
Smock	559	32.9
Early Michigan	721	32.9
Poole's Favorite	901	38.5
Sneed	641	41.4
Carman	617	41.9
Gold Drop	744	42.8
Snow	895	44.2
General Lee	529	46.5
Hills Chili	647	50.3
Salway	675	50.9
Early Tillotson	541	54.7
Krummel October	539	56.5
Alexander	532	56.9
Ortiz	1930	57.1
Triumph	1111	59.1
Rareripe	566	59.3
Crosby	896	60.8
Family Favorite	1012	61.0
Captain Ede	704	63.4
Crawford's Early	994	64.1
Bokhara	513	67.4
Briggs' Red	470	67.4
Elberta	1680	67.8
Oldmixon Cling	2080	69.0
Thurber	519	69.1
Henrietta	592	73.9
Glove	889	76.7
Oldmixon Free	1040	78.0
Fitzgerald	641	80.0
Kalamazoo	1249	80.7
Heath Cling	726	81.6
Champion	608	82.2
Early Bernard	752	82.5
Shipley Red	542	88.0
Yellow St. John	512	88.8
Crawford's Late	677	90.2
Susquehanna	692	96.9

Variety	Number Buds Counted	Percentage Buds Killed
February 4, 1907. Temperature +1° F.		
Early Tillotson	535	18.8
Gold Drop	765	31.5
Lewis	162	42.5
Oldmixon Cling	1442	44.4
Triumph	642	44.8
Poole's Favorite	1003	54.1
Elberta	409	59.9
Smock	804	61.7
Oldmixon Free	504	90.8
February 2, 1908. Temperature +2° F.		
Crawford's Early	250	18.0
Elberta	977	35.3
Kalamazoo	1104	43.4
Family Favorite	671	44.9
Oldmixon Free	11242	45.7
Ortiz	1177	50.8
Sneed	1662	57.5
Dewey Cling	1204	80.9
January 12, 1909. Temperature –11° F.		
Thurber	975	55.2
Early Michigan	463	63.0
Heath Cling	455	74.7
Hills Chili	493	75.2
Smock	230	78.6
Salway	1864	79.1
Ortiz	2355	80.8
Sneed	333	81,8
Crosby	520	85.3
General Lee	426	87.7
Family Favorite	843	89.9
Dewey Cling	484	89.9
Champion	550	91.2
Early Bernard	544	92.2
Bokhara	1792	92.2
Triumph	753	93.3
Oldmixon Cling	2994	96.3
Elberta	6634	97.3
Fitzgerald	249	97.7
Crawford's Early	848	98.6
Crawford's Late	464	99.5
Ringold	1030	99.5
Oldmixon Free	997	100.0
Golden Gate	167	100.0

Variety	Buds Number Counted	Buds Percentag Killed
December 9 and 29, 1909. Temperature -5° F. and -8° F.		
Chinese Cling	75	2.6
Family Favorite	200	3.0
Triumph	174	7.4
Hiley	150	11.3
Sneed	185	12.9
Briggs' Red	100	13.0
Early Michigan	126	14.2
General Lee	150	14.6
Salway	559	14.9
Oldmixon Free	200	15.5
Alton	250	16.4
Rice's Seedling	300	17.0
Oldmixon Cling	200	21.0
Crosby	148	22.9
Elberta	400	24.0
Ortiz	200	27.0
Fitzgerald	100	31.0
Heath Cling	141	31.2
Champion	150	33.3
Crawford's Late	146	44.5
Bokhara	150	51.3
Early Bernard	100	52.0
Kalamazoo	150	52.6
January 3, 1911. Temperature -8° F.		
Triumph	275	29.8
Salway	309	34.9
Henrietta	237	43.4
Krummel October	261	45.9
Crosby	530	52.6
Carman	203	52.7
Heath Cling	234	58.1
Captain Ede	244	58.1
Early Bernard	253	59.2
Sneed	383	61.3
Kalamazoo	269	74.3
Fitzgerald	253	79.0

It will be seen that on January 12, 1909, practically all the buds were killed except on the most hardy varieties by a temperature of -11° F. In fact fewer peaches were borne at Columbia following the winter of 1908-09 than following the winter of 1904-05 when the temperature fell to -25° F. on February 13. A temperature of -12° F. on February 2, 1905, killed only a very small percentage of the buds of such tender varieties as Yellow St. John. It may be said too that a temperature of -15° F. on January 7, 1912, killed practically every peach bud at Koshkonong, Missouri. By referring

to the adjoining chart, showing maximum and minimum temperature curves from December 1st to the date of killing each year at Columbia and at Koshkonong, and for the year 1908-09 and 1909-10 at Geneva, New York, it will be seen that there was not more warm weather to start the buds preceding the freeze of January 12, 1909 at Columbia or that of January 7, 1912, at Koshkonong, than preceding the freeze of February 13, 1905 at Columbia.

It would hardily seem possible that the buds in either case could have been started into slight growth preceding the freeze. Buds start very slowly even at high temperature early in January. By referring to the chart it will be seen that the low temperature of January, 12, 1909, came suddenly, following high temperature, while that of February 13, 1905, came following forty-two days of rather low temperature. For sixteen days the maximum temperature did not go above the freezing point.

There seems to be two possible explanations for the greater hardiness of the fruit buds during the seasons like that of 1904-05 in Columbia. It is possible that by long exposure to low temperature the buds develop the ability to withstand lower temperatures. Since freezing to death of plant tissue seems to result from withdrawal of water from the cell, the fact that slow drying out of the tissue (see Table 19) increased the hardiness of the buds would lend weight to this theory. The cells would be greatly desiccated during the period of low temperature which preceded the freeze of February 13, 1905.

The other possible explanation of this greater hardiness of the fruit buds in 1905 is the very slow falling of the temperature (see Table 20). It will be remembered that the greatest harm resulted when the rapid temperature fall occurred for the first fifteen degrees below the freezing point, though rapid temperature fall during the last ten or fifteen degrees before the killing temperature was reached also caused greater killing than where the temperature fell slowly from the freezing point (see Table 21). This station was unable in its laboratory experiments to maintain a continuous low temperature that would approximate temperature conditions that prevailed outside when buds withstood such extremely low temperatures as in February, 1905. However, buds of varieties known to show greater resistance on such winters were not killed by temperatures that killed buds of varieties like Elberta, known to be tender. The freezing tests in the laboratory then were tests of the relative hardiness of the buds, either of different varieties or of the same variety differing in hardiness on account of local conditions. Twigs to freeze were obtained from New York, from South Missouri, and from

Georgia, through the kindness of Professor U. P. Hedrick of the Geneva, New York, Experiment Station; of the Ozark Fruit Farm Company of Brandsville, Missouri; and of Professor H. P. Stuckey of the Georgia Experiment Station. The following table gives the results of our freezings:

TABLE 40. SHOWING THE RELATIVE HARDINESS OF ELBERTA PEACH FRUIT BUDS FROM NEW YORK, SOUTH MISSOURI, CENTRAL MISSOURI AND GEORGIA.

Buds from:	Date	Temperature	Number Frozen	Percentage Killed
Geneva, New York	Nov. 27,'08	-25	55	100
Columbia, Missouri	Nov. 27,'08	-25	63	100
Geneva, New York	Nov. 27,'08	-17.5	121	33.8
Columbia, Missouri	Nov. 27,'08	-17.5	147	68.7
Geneva, New York	Dec. 12,'08	-20.5	152	59.8
Columbia, Missouri	Dec. 12,'08	-20.5	111	37.8
Geneva, New York	Dec. 24,'08	-20.5	129	96.9
Columbia, Missouri	Dec. 24,'08	-20.5	283	67.5
Geneva, New York	Dec. 26,'08	-21.5	195	59.4
Columbia, Missouri	Dec. 26,'08	-21.5	216	33.6
Geneva, New York	Dec. 28,'08	-21	76	81.5
Columbia, Missouri	Dec. 28,'08	-21	194	57.2
Geneva, New York	Jan. 1,'09	-20.5	73	100
Columbia, Missouri	Jan. 1,'09	-20.5	178	57.8
Brandsville, Missouri	Jan. 1,'09	-20.5	95	40.0
Geneva, New York	Jan. 1,'09	-22	85	100
Columbia, Missouri	Jan. 1,'09	-22	158	83.5
Brandsville, Missouri	Jan. 1,'09	-22	110	44.5
Geneva, New York	Jan. 4,'09	-21.5	32	100.
Columbia, Missouri	Jan. 4,'09	-21.5	76	59.2
Brandsville, Missouri	Jan. 4,'09	-21.5	81	34.5
Geneva, New York	Jan. 4,'09	-22	26	100
Columbia, Missouri	Jan. 4,'09	-22	87	78.1
Brandsville, Missouri	Jan. 4,'09	-22	79	35.4
Geneva, New York	Dec. 17,'09	-21	159	83.0
Columbia, Missouri	Dec. 17,'09	-21	282	98.2
Experiment, Georgia	Dec. 17,'09	-21	124	98.3
Geneva, New York	Jan. 19,'10	-19.5	115	91.3
Columbia, Missouri	Jan. 19,'10	-19.5	107	92.5
Experiment, Georgia	Jan. 19,'10	-19.5	84	98.8
Geneva, New York	Feb. 22,'10	-22	130	83.3
Columbia, Missouri	Feb. 22,'10	-22	219	40.6
Geneva, New York	Feb. 25,'10	-21	15	60.0
Columbia, Missouri	Feb. 25,'10	-21	200	20.0
Experiment, Georgia	Feb. 25,'10	-21	82	97.5
Geneva, New York	Feb. 25,'10	-21	17	76.4
Columbia, Missouri	Feb. 25,'10	-21	127	58.2
Experiment, Georgia	Feb. 25,'10	-21	74	94.5
Fifteen freezings Geneva buds, average				81.8
Fifteen freezings Columbia buds, average				67.2
Four freezings Brandsville buds, average				38.6

It should be said that there were more immature or partially developed buds that were killed by a rather high temperature on the twigs from Geneva than on the twigs from either Columbia or Brandsville, which probably explains the higher percentage of buds killed on the Geneva twigs.

It will be seen that except when the freezings were late in February when buds in Missouri had been started into growth by warm days, the buds from New York were not more hardy than those of the same variety from Columbia. In the preceding chart will be found curves showing maximum and minimum temperatures for Geneva, New York; for Koshkonong, Missouri, six miles from Brandsville, Missouri; and for Columbia, Missouri.

It will be seen that the buds from Geneva, New York, had been exposed to lower temperature and to more continuously low temperature preceding the freezing. Yet when they are thawed before freezing and the temperature fall is equally rapid, there seems to be no difference between their hardiness and the hardiness of buds from central or southern Missouri. It is possible that the buds from New York were started into some growth in transit shipment having been made by express. However, the buds from Bransdville, Missouri, came in the same way and, on account of poor railway connections into Columbia from the South were about as long in coming. If they were not as long in coming, they were kept in a rather warm basement room until the New York twigs came. While the data are not such that absolute conclusions could be drawn, at the same time they certainly seem to suggest that the buds from New York had not acquired appreciably greater hardiness due to their having been previously exposed to low temperature. It seems possible that the buds are more resistant to a low temperature at the end of a long cold period than are equally dormant buds to a low temperature that comes with a sudden drop, not so much because of a greater resistance of the protoplasm brought about by prolonged exposure to low temperature as because of the very slow temperature fall. If this be true, a freeze following a thaw in winter should result in greater injury than if there were no thaw, even if the temperature during the thaw does not go high enough to cause growth. This seems to be the experience of growers in the North. Letters from men in Connecticut, New Hampshire, and the peach regions of Canada state that with them killing of the buds generally occurs when the cold period follows a thaw. It would hardly seem possible that weather warm enough to start growth would be experienced in those sections. It would seem more probable that the killing results from

the rapid temperature fall, while the greater resistance of the buds following a prolonged cold period is due to the very slow temperature fall with the resulting slow withdrawal of water from the cells, especially while the temperature is still near the freezing point. (See Table 21.)

The condition of the tree when it enters the winter should not be lost sight of in considerations such as the above on the killing from cold in winter. As mentioned previously, maturity plays an important part in the resistance of winter tissue to low temperatures. It may be said, however, that reference is had to the same trees for 1905 as for 1909. They were older in 1909 and were unquestionably as mature. In fact in 1909 there was no apparent difference between the hardiness of buds on the most vigorously growing trees and those growing most slowly in this orchard, indicating that all the trees went into the winter in good condition. That the condition that favors greatest hardiness of buds is one of greatest maturity is apparently common knowledge among peach growers in northern sections. On each such winter in the Missouri Experiment Station orchard these trees that had ceased growing and become dormant rather early the season before carried the largest number of buds through the extreme cold uninjured. The same phenomena were observed in Southwest Missouri following the winter of 1911-12 when there were no warm days to start the buds preceding the extreme cold that killed them. In this case only those trees that were large and matured early and had a large amount of small growth down in the tree had any large percentage of buds to survive. These same phenomena have been observed in orchards on other years in Missouri. However, the average buds on a later maturing tree do not seem to be appreciably less hardy than the average buds on earlier maturing trees. In nearly all cases those buds that survived were buds located on small spurs where there would be a whorl of three or four leaves with only one or two buds on the spur, and there are few such buds on a heavily pruned late maturing tree. It was shown in Bulletin No. 74 of the Missouri Experiment Station that generally the largest percentage of buds to survive cold are on the base of the twigs of mature size; the next largest on these small spurs mentioned above; and the smallest percentage to survive will be on the ends of the twigs. However, with extreme cold that will kill all of the buds at the base of the main twigs or practically all of them, there will often be a few on the spurs; that is, the buds on these spurs vary more as to hardiness than do the buds at the base of the whips. This would naturally be expected since the condition of growth with

reference to light, etc., will vary more. While the percentage of buds surviving on the tree when enough are killed that practically all left are on these small spurs, would naturally be very small, it should be remembered that only a very small percentage of buds on a large healthy tree would be sufficient for a crop that would be profitable to handle. Under conditions when the buds are killed in a fully dormant state, or are killed after some starting following a warm period coming late enough in the season so that the rest period does not affect the amount of starting, the best plan for handling the trees is to prune them down to a size that can be conveniently handled in spraying, pruning, picking, etc., and to practice a system of pruning and cultivation such that they will cease growing as early as August in central Missouri.

Varieties With Most Hardy Fruit Buds When Fully Dormant. There is a great difference in the degree of cold that different varieties will withstand even when fully dormant. Hedrick gives a list of the hardiest varieties for New York and for Michigan, basing his conclusions on letters received from a large number of New York and Michigan growers. The New York growers name Crosby, Hills Chili, Triumph, Gold Drop, Stevens' Rareripe, and Kalamazoo as being the most hardy in bud, Crosby and Hills Chili being listed by a much larger number of growers than either of the other varieties. Hills Chili, Gold Drop, Crosby, Kalamazoo, and Bernard are the hardiest varieties, according to the opinion of the Michigan growers. Waugh lists Greensboro as one of the hardiest under Massachusetts conditions. Growers in the northern part of Missouri have also found Greensboro probably the hardiest peach in bud that they have grown. Judging from years when the buds were killed without any starting into growth by previous warm periods, Hills Chili, Lewis, Thurber, Gold Drop, Triumph and Crosby have been among the very hardiest in bud in Missouri. Lewis is a seedling of Hills Chili. Mr. R. F. Howard, formerly of the Nebraska Experiment Station, and others in Nebraska place Russell,[1] another seedling of Hills Chili, as one of the very hardiest of peaches in bud, as well as in wood.

In Missouri, besides Greensboro and Thurber, Carman, Belle of Georgia, General Lee, and Chinese Cling, and some other varieties of the Chinese Cling group, have been more hardy in bud even under fully dormant conditions, than the majority of the well known varieties. The Green Twig group, especially Snow and Rice's Seed-

[1]Yearbook, U. S. Dept. Agr. 1911, p. 429. (Bibl. No. 109).

ling, have been found hardy under the same conditions. Champion is also above the average in hardiness under fully dormant conditions, so far as observations in Missouri indicate.

Of the more tender varieties when fully dormant Hedrick lists, from the opinion of New York and Michigan growers, Crawford's Early, Crawford's Late, Chairs Choice, Reeves' Favorite, and Elberta.

In Missouri these varieties are among the most tender on such years under Missouri conditions, with other peaches of the same type as Golden Gate running even more tender, and Oldmixon Free and Cling and the Heath Cling group, and Fitzgerald and Early Bernard, being slightly more hardy.

Rest Period of Peach Fruit Buds. During some of the seasons mentioned above, especially that of 1905-06, a large percentage of the buds were killed at a high temperature because they had been previously started into growth by warm weather. By referring to the temperature chart it will be seen that on many years in Columbia, and on a large majority of years at Koshkonong in the extreme southern part of Missouri, the temperature for December, January and February will average as high as for those three months in Columbia in 1905-06.

During the writer's observations there has very seldom been a year when buds in the peach section of southern Missouri have not been started sufficiently by February 1 to be killed by a temperature considerably higher than would be required to kill buds in northern Missouri, or certainly in Michigan, New York or New England on the same date.

VARIETIES WITH THE LONGEST REST PERIODS.

Any one who has had experience with a large number of varieties of peaches in a climate like that of southern Missouri has observed that there is a wide difference between the amount of starting by February 1 on different varieties. Thus it will be seen by referring to Table 39 that a smaller percentage of buds were killed on February 5, 1906, by a temperature of -3° F., following a warm period, on General Lee, Chinese Cling and Sneed of the Chinese Cling group, and the Green Twig varieties such as Snow and Ortiz, and on Lewis and Early Michigan of the Hills Chili group, than were killed on varieties like Crawford's Early, Elberta, Fitzgerald and the Heath Cling varieties.

Experiments at this station have indicated that the reason for this is because these varieties have a longer rest period. Attempts to force the buds of various varieties into growth in the early part of the dormant season, by keeping the twigs in the greenhouse with their bases in water, were published in Bulletin No. 74 of the Missouri Experiment Station. The following table summarizes those results for some of the different types of peaches, giving also the percentage of the buds killed by a temperature of -3° F. on February 3, 1906, when the killing at so high a temperature was due to the buds having been started into growth by previous warm days.

TABLE 41. PERCENTAGE OF BUDS THAT COULD BE STARTED INTO GROWTH BY DECEMBER 12, AND DECEMBER 22, 1906, ON VARIETIES OF HILLS CHILI, CHINESE CLING, GREEN TWIG AND OTHER GROUPS.

Variety	Percentage of buds killed in 1905-06	Percentage of buds started by Dec. 12, 1906	Percentage of buds started by Dec. 22, 1906
HILLS CHILI TYPE			
Hills Chili	53.0	5.2	No data
Lewis	25.9	0.0	39.0
Early Michigan	32.9	5.7	42.4
Average	37.2	3.6	40.7
CHINESE CLING TYPE			
Chinese Cling	30.7	0.0	0.0
General Lee	46.5	0.0	0.5
Sneed	41.4	0.0	8.0
Carman	41.9	No data	25.0
Connett	40.0	0.0	0.0
Family Favorite	61.0	0.0	7.0
Elberta	67.8	No data	56.0
Average	47.0	0.0	13.8
Average (excluding Elberta)	43.6	0.0	6.7
GREEN TWIG VARIETIES			
Snow	42.0	0.0	12.0
Ortiz	57.1	0.0	5.4
Average	49.5	0.0	8.7
HEATH CLING TYPE			
Heath Cling	81.6	17.5	86.0
Dewey Cling	74.8	36.7	88.0
Hubert Cling	77.2	27.4	85.0
Ringold	83.0	30.0	88.0
Average	79.1	27.9	86.7
OTHERS OF PERSIAN RACE			
Elberta	67.8	No data	56.0
Crawford's Early	64.1	No data	54.1
Crawford's Late	90.2	No data	59.0
Oldmixon Free	78.0	No data	98.0
Foster	87.0	No data	83.0
Crosby	60.9	22.8	90.0
Susquehanna	96.9	10.0	65.0
Wheatland	95.4	No data	86.0
Golden Gate	89.7	17.7	58.0
Triumph	59.1	0.0	7.5
Average	78.9	12.6	65.7

It will be seen that especially the Chinese Cling group of peaches and the green twig varieties have a long rest period and can not be readily pushed into growth by warm periods earlier than about January 20th, while such varieties as Crawford's Early, Foster and all of the Heath Cling varieties could be much more readily pushed into growth in the early season. Fitzgerald and Early Bernard are not included in these experiments, but experience with them proves that they have as short a rest period as Crawford's Early, and are equally tender under Missouri conditions. Elberta, a Chinese Cling seedling, the other parent of which is thought to be Crawford's Early, has a short rest period like Crawford's Early, while Carman resembles the Chinese Cling in bud habits. Since the publication of Bulletin No. 74, there has been opportunity to observe the pushing during late February on Carman as compared with Elberta in southern Missouri, and uniformly the Elberta pushes much more rapidly during January and February, and even March, than Carman, and on nearly every year it blooms earlier, though in North Missouri where peaches bloom later and the effect of the rest period will thus be entirely eliminated before blooming time, Carman and Elberta are likely to bloom together.

EFFECT OF VIGOR OF THE TREES ON THE REST PERIOD.

It was found as published in Bulletin No. 74, Missouri Experiment Station that prolonging the growth of peach trees in the fall will prolong the rest period so that the fruit buds are not so liable to be killed by cold periods following warm periods. This prolonging the growth in the fall was generally accomplished by pruning the trees severely, in this case two years before those tests were made. This caused them to grow more vigorously throughout the summer and to continue growth later and to hold their leaves late in autumn. While the more vigorous growth continued through the second summer after the pruning, the additional vigor over the unpruned trees was not so great.

To test the effect of this additional vigor on the rest period, twigs gathered on various dates from November 23 to January 13 were forced from two to three weeks in the greenhouse. Following is a summary of the table published in Missouri Experiment Station Bulletin No. 74, giving the result of these tests made during the season of 1906-07. The vigorous, pruned trees are termed "cut back" trees.

Average percentage started on trees making large growth (cut back)..20.5
Average percentage started on trees making small growth (not cut back)..31.2
Number of varieties in which trees not cut back started first...20
Number of varieties in which trees cut back started first........ 3
Number in which both started about equally.................. 4

Quoting from the publication referred to:

"It will be seen that only two-thirds as large a percentage of buds started on cut back trees as on trees not cut back. It would be expected then that when ninety per cent of the buds had started on trees making small growth, only sixty per cent of those on trees making a large growth would be started. This is borne out in the above table. If we take the average of buds started on twigs taken December 22nd, or later; that is, when the resting period is nearly ended, we have:—

"For trees making large growth (cut back) 28.3 per cent started; for trees making smaller growth (not cut back) 48.6 per cent started.

"Taking only those varieties in which one tree had sixty per cent of the buds started, and therefore may be considered to have finished its resting period, we have as an average:—

"On trees making large growth (cut back) 44.3 per cent of the buds started;
"On trees making smaller growth (not cut back) 83.4 per cent of the buds started."

Results during the previous season when the difference in vigor of the trees was greater, were even more conclusive though perhaps not enough buds were used in the experiment. Thus with Elberta buds on twigs gathered December 2, 1905, 66 per cent of those from slowly growing trees clearly showed swelling by December 21, while none from the vigorously growing cut back trees showed any swelling. Even when the buds from vigorous trees were counted as started, they had not generally made as much growth as had those from weak trees. It should be said, too, that the trees listed as weak trees were of average vigor when compared with those of most commercial orchards.

Since the publication of that bulletin this station has made observations on the effects of severe pruning and late growth on the rest period of buds in the extreme southern portion of Missouri where there are many days in January and February warm enough to start

growth. It has been generally found that the buds on weak trees are more forward than on trees that have grown late in the fall. At Doniphan, Missouri (in one of the extreme southern counties) during the spring of 1908 in an orchard owned by a Mr. Neal, old Elberta trees that had been weakened by late summer pruning and others that had not been pruned at all were in full bloom by March 15, while young Elberta trees that had been severely pruned the spring and late winter before were not yet in bloom, being apparently at least one week more backward in blooming than the weakly growing trees. Other orchards in the same community showed similar conditions. It should be said, too, that this was not an abnormally early bloom for extreme southern Missouri.

During the spring of 1910 a number of Elberta peach trees were pruned back very severely in the orchard of the Ozark Fruit Farm Company at Brandsville, Howell County. The following winter was so abnormal that nearly all Elberta trees were almost in full bloom by February 22, when a temperature of 14° F. was experienced. Of course the bloom and some of the unopened buds on such trees were killed. At that time the fruit buds on these severely pruned trees that had grown late in the fall were not open, and they suffered much less injury than did buds on trees not cut back.

Again on March 16 a temperature 20° F. was experienced. Buds on these cut back trees had not yet reached the stage of development that had been reached by trees not so treated by February 22, the temperature between those dates being too low for much growth to take place. The following table gives the percentage of buds killed on the severely pruned and on the unpruned trees by the freeze of February 22, and by the freeze of March 16.

TABLE 42. SHOWING THE PERCENTAGE OF BUDS KILLED AT BRANDSVILLE, MISSOURI, BY THE FREEZES OF FEBRUARY 22 AND MARCH 16, 1911, ON SEVERELY PRUNED AND UNPRUNED TREES.

Treatment	Total Number of buds	Percentage of Buds Killed by Freeze of Feb. 22, 1911	Percentage of Buds Killed by Freeze of Mar. 16, 1911
Not cut back	104	85.6	98.08
Cut back	183	48.1	81.9

Thus 18.1 per cent of the buds on these cut back trees were still alive after the two freezes. These trees set practically a full crop while trees around them bore not more than one or two peaches to the tree. On the same year, trees heavily pruned the previous spring at Doniphan, Missouri (another southern county), were more than three weeks later in blooming than trees not so treated, as reported by Mr. J. R. Stevens.

The rest period can also be as readily prolonged by fertilizing with a nitrogenous fertilizer, thus prolonging the growth into the fall. In the Brandsville orchard mentioned above, in 1910 a plot of trees was heavily fertilized with ammonium sulphate. One plot of thirty trees received 100 pounds and another plot of sixty trees received 100 pounds. The following table gives the percentage of buds killed on those trees receiving the heavy applications of fertilizer on February 22 and on March 16, and also the percentage killed on adjoining trees not so treated, and on trees fertilized lightly with sodium nitrate in 1909 and in 1910:

TABLE 43. SHOWING THE PERCENTAGE OF BUDS KILLED AT BRANDSVILLE, MISSOURI, BY THE FREEZES OF FEBRUARY 22 AND MARCH 16, 1911, ON TREES FERTILIZED WITH NITROGEN AND TREES NOT SO FERTILIZED.

Treatment	Total Number of Buds	Percentage of Buds Killed by Freeze of Feb. 22, 1911	Percentage of Buds Killed by Freeze of Mar. 16, 1911
Fertilized with Ammonium Sulphate	312	44.6	77.6
Check, not fertilized	188	91.5	98.4
Fertilized with Sodium Nitrate 1⅔ lbs. to the tree in 1909 and 1 lb. to the tree in 1910	225	80.4	87.1

On the trees fertilized heavily the spring before with ammonium sulphate a percentage of buds large enough for a full crop was left after both of these freezes, and the trees set and ripened a full crop of fruit, while the adjoining trees had nothing. Trees fertilized with sodium nitrate, but not so heavily, did not show such marked results, and yet there were enough buds left for a fair crop, if all the orchard

had set as much so the activities of the curculio would not have been concentrated on so small an area.

It may be said also that trees on another plot fertilized with sixty-three pounds of sodium nitrate to thirty-six trees in March, 1909, had a smaller percentage of buds killed during the winter of 1909-10 and set a heavier crop in 1910. From these results it is evident that where there are a large number of warm periods in the early part of the winter before the rest period is entirely ended, anything that prolongs the growth in the fall greatly reduces the percentage of buds killed. In fact from the southern tier of counties in Missouri, south, even where the freezes follow warm days as late in the season as February, it will still be a benefit to have the trees grow late in the fall, as witness later blooming of the more vigorous trees mentioned above.

It should be said with reference to the ending of the rest period, that so far as we can tell, this does not occur at a definite time, but buds that will push very rapidly when taken into a warm greenhouse in March can be pushed in January or early February, but not nearly so rapidly; so that whatever the ending of the rest period is, it is certainly a gradual process. While the differences between the rate of pushing on vigorous and weak trees would be smaller following warm days late in the season, say in February, than as early as December and January, yet with trees in extreme southern Missouri, there are some differences to be observed as late as February or March as mentioned above. This was certainly true in the case of blooming of peaches in February, 1911, when the more vigorous trees did not bloom until more than a month later than weak trees bloomed. However, in years when the bloom is rather late there will be little or no difference between the blooming of vigorously growing and weakly growing trees. Thus in the spring of 1913 the full bloom on Elberta trees that were fertilized with sodium nitrate in the spring of 1912 and those that were not, came at practically the same time, which was approximately April 5. Carman, though, was at least four days later in coming into full bloom than Elberta, and Carman from our experience has a longer rest period than Elberta.

As far north as Columbia, Missouri, where the peach bloom is never earlier than March 20, and is usually in April, weak trees have never bloomed earlier than vigorous trees, and varieties like Carman, Chinese Cling, etc., have never bloomed during our observations later than trees with a shorter rest period. Thus neither by forcing late growth to prolong the rest period nor by choosing varieties, such as those of the Chinese Cling group, with long rest periods,

can the date of blooming often be appreciably affected as far north as Central Missouri. In southern Missouri, on account of the protection from early autumn frosts rendered by the excellent air drainage and on account of its being further south, the trees grow later in autumn and for the same reasons, blooming is likely to occur from a week to occasionally six or seven weeks earlier than in central Missouri. Thus the season there between the beginning of dormancy and blooming time is often short enough that the influence of the rest period may be observed even at blooming time. Trees of varieties with a long rest period or trees that grow late in autumn will bloom later, as in the case of the pruned and fertilized trees mentioned above.

Relation of Thinning the Fruit to Hardiness. Another phase of orchard practice with which it seems it would be possible to influence the rest period, is thinning the fruit. In tests reported in Bulletin No. 74 of the Missouri Experiment Station where trees had one-half of the fruit thinned and the other half left to bear a full crop, out of five trees so treated in each case during the following winter a larger percentage of buds were killed on the side that was not thinned than on the side that was thinned, and where the thinning was very heavy or where all of the fruit was taken off, the difference was very marked. The following table gives the results:

TABLE 44. SHOWING EFFECT OF THINNING ON HARDINESS, BUDS STARTED INTO GROWTH BY WARM PERIOD BEFORE END OF REST PERIOD.

Variety	Treatment	Number of Buds Counted	Percentage of Buds Killed
Seedling	Fruit thinned	1529	18.5
Seedling	Fruit not thinned	1657	58.9
Elberta Seedling	Fruit thinned	1020	31.6
Elberta Seedling	Fruit not thinned	1146	36.7
Oldmixon Cling	Fruit thinned	1442	44.5
Oldmixon Cling	Fruit not thinned	1149	53.4
Poole's Favorite	Fruit thinned	818	41.7
Poole's Favorite	Fruit not thinned	807	52.8
Poole's Favorite	Fruit thinned	1563	40.9
Poole's Favorite	Fruit not thinned	1200	55.4
Average (thinned)			35.4
Average (not thinned)			51.4

During the season of 1908 this study was continued and we have the results for the freeze of January 12, 1909, where the killing was not caused by cold periods following warm periods, but by cold periods when the buds were fully dormant. In this case there was no difference in the hardiness due to thinning, as the following table shows:

TABLE 45. SHOWING THE PERCENTAGE OF BUDS KILLED ON THINNED AND UNTHINNED LIMBS OF TREES WHEN THE BUDS HAD NOT BEEN STARTED INTO GROWTH BEFORE THE FREEZE.

Variety	Date	Number of Buds Thinned	Percentage of Buds Killed. Thinned.	Number of Buds Not Thinned.	Percentage Buds Killed. Not Thinned.
Salway	Jan. 12,'09	345	74.5	425	84.7
Ringold	Jan. 12,'09	397	99.8	289	98.6
Family Favorite	Jan. 12,'09	274	90.8	569	89.1
Elberta	Jan. 11,'09	323	99.4	334	94.4
Elberta	Jan. 12,'09	613	85.3	454	86.5
Elberta	Jan. 12,'09	538	99.9	608	100.0
Triumph	Jan. 12,'09	292	92.1	242	90.9
Magnum Bonum	Jan. 12,'13	308	100.0	250	99.2
Crawford's Early	Jan. 12,'09	412	99.2	436	97.9
Alexander	Jan. 12,'09	230	94.7	194	91.2
Oldmixon Free	Jan. 12,'09	152	100.0	182	100.0
Hills Chili	Jan. 12,'09	397	94.9	405	95.0
Bonanza	Jan. 12,'09	421	95.9	352	96.8
Early Michigan	Jan. 12,'09	145	84.8	496	82.8
Early Michigan	Jan. 12,'09	243	78.6	154	79.8
Total number buds		5090	....	5390	
Average		....	93.2	....	92.5

During the same season artificial freezings of buds from the thinned and unthinned sides of these trees were run, and in this also there was no constant difference between the percentage of buds killed from thinned and unthinned limbs. These results suggest that thinning has its effect on the rest period rather than on the intrinsic hardiness of the buds. Where the tree is bent under a heavy load and under the strain of bearing a heavy crop, as when it is not thinned, the moisture supply probably being partially shut off, the same condition will prevail, at least to some extent, as when the trees are not cultivated; they will become dormant earlier and end their rest period earlier. Thus thinning, like heavy pruning and fertilizing with nitrogen can be expected to increase the hardiness of peach

fruit buds only in climates like that from Central Missouri South, where there is likely to be weather warm enough to start the buds into growth before the effect of the rest period ends.

It may be said also, especially concerning thin soils such as are to be found in the Ozark regions of Missouri and Arkansas, if the tree is permitted to bear an exceptionally heavy crop, it sets a much smaller number of fruit buds. While experiments have not always indicated that this is true with apples, any one who has had an opportunity to observe a considerable number of peach orchards where only part of the trees have been thinned will be readily convinced that it is true with peaches. This fact has its bearing on the problem of killing from cold since with a very light set following a heavy crop, if as many as 75 per cent of the buds are killed, there will not be enough buds for a good crop, while if the trees were thinned, 25 per cent of the buds would be enough for a heavy crop. By consulting Table 39 it will be seen that in a large number of years as many as 75 per cent of the fruit buds are killed on Elberta trees. In sections like South Missouri where the rest period seriously affects the amount of bud killing, thinning, when necessary, would thus seem to affect the size of the following crop on nearly every year.

The greater hardiness in late winter of fruit buds on severely pruned trees and on trees fertilized with nitrate, like those mentioned above, represents a difference in time of ending the rest period between fruit buds on very vigorous trees and on trees of medium vigor. Where the rest period was prolonged by thinning, the difference in hardiness represents a difference in time of ending the rest period between fruit buds on trees of medium vigor and on trees in a rather weak condition. In case of trees making a weak growth for any reason, as compared with trees making a moderately vigorous growth, so far as our observations have gone, the differences while not so great, are yet often apparent. In a number of years the buds or blossoms have been so nearly all killed that the crop in extreme South Missouri on weakly growing trees, amounted to nothing, while trees of medium vigor, like an average six-year-old tree, bore good crops in the same years.

In attempting to increase the hardiness of peach buds under the climatic conditions prevailing in southern Missouri, by largely increasing the vigor of growth over the average growth, several limiting factors must be considered. In the case of pruning, such large increase in vigor of growth can practically be secured only following winters or springs when the fruit buds or blossoms have been killed, since this cutting back so severely in other years would cause

the loss of the crop following the spring it is done. However, in the Missouri peach section on all except the high land, at least, the crop is likely under average conditions to be lost probably half of the time and in such years it certainly is advisable to give the trees rather severe cutting back. In none of the experiments above mentioned, however, has it proved an advantage to cut the limbs back so severely that only short stubs, say two or three feet long, are left. In this case the growth will be so vigorous and there will be so much shade that very few fruit buds will form, during the following summer. The tree will also be so greatly reduced in size that even though a crop may be secured the year following, there will be bearing surface for only a small crop. Cutting back into two-year-old wood or sometimes into three-year-old wood and shearing the small growth off the limbs so that there will be only stocky, vigorous twigs to form in summer, has secured the best results. The cutting back should be light enough that buds will form practically to the base of all of the new twigs. With pruning like this a large bearing surface is left and a large number of buds generally set. Observation has uniformly indicated that following periods when part of the buds are killed, most of the fruit will be borne on the twigs down along the limbs rather than on the very vigorously growing twigs that form along the top of the limbs. No such twigs will be formed along the limbs where the tree has been given too heavy pruning as where the limbs are left only three to five feet long.

For these southern Missouri conditions the pruning in years when there is a crop should be as severe as can be given and yet secure a maximum crop of the best quality of fruit from the tree. If this is practiced there will be later pushing of buds the following winter and in some years a slightly later blooming on trees so pruned than on trees that have had less pruning. However, where the soil is very thin it may be impossible to keep the trees in a sufficiently rapidly growing condition to secure a prolonged rest period without too greatly reducing the size of the tree. In this case the vigor should be kept up by a combination of pruning, cultivation and fertilizing with nitrogen (or a complete fertilizer if it is proved that other elements than nitrogen are needed in the given soil).

In fertilizing with nitrogen, however, to keep up the vigor of the trees, caution should be used because heavy applications of nitrogen-bearing fertilizers seriously injure the color of the fruit borne the summer following, and cause fruit to rot. This has been our experience each year at Brandsville, Missouri. Increasing the vigor by pruning does not have this effect to any appreciable extent, but generally

tends to improve the quality of the fruit by increasing its size. Fertilizing with nitrogen should be as light as it is possible to give and yet keep up proper vigor and size of the tree by combining nitrogen fertilizing with pruning and good cultivation. This may be said, however, that since it has become the regular practice to spray peaches, this injury to color is not so serious as it formerly was because the spraying burns into the peach generally a rather brilliant color. If in addition to spraying the fruit is thinned and the trees kept well open, the injury to color and diminished resistance to rot from the use of nitrogen is not so great.

Probably under average conditions a good system to follow would be to fertilize with the equivalent of one or one and one-half pounds of sodium nitrate to the tree and to prune as much as possible without reducing the crop of high-grade fruit in any year. The nitrogen should be applied not every year but only often enough to maintain the desired size of the tree, since the pruning has a dwarfing effect. It may be observed that inducing vigorous growth will cause a late growth in autumn; and that therefore the fruit buds and wood will not be in a desirably mature condition for winter. This is certainly true in some northern sections and in case of buds has in several years since 1901 been true in Columbia. Since 1901 there has probably been only one winter when a larger percentage of buds were killed on late growing than on early maturing trees in extreme southern Missouri, and even in that year-1911-12—the wood of the vigorous trees best recovered from the effects of the winter. It should be remembered that in southern Missouri the soil is so light and the season so long that it is not easy to prolong the growth of a peach tree more than two years from planting enough to prevent its going into winter in the best condition for that section.

It may be said that before recommending a method like this for increasing the hardiness of buds, it probably should be tested out during a period of ten or twelve years so that observations will extend through enough seasons that one may be sure he has struck an average. However, this may be said, that the methods here recommended are certainly the best for the orchard, regardless of the effect on the hardiness of the tree. Fertilizing with nitrogen has caused the tree to resist certain diseases like shothole fungus, as well as to recover from the effects of winter freezes, heavy crops, etc., and has, of course, given a larger tree that could bear a much heavier crop. Heavy pruning has had similar effects except that

it generally tends to reduce the size of the tree, though in very thin, dry soil, heavy pruning has also increased the size of the tree.

Whitewashing Twigs to Retard Bud Growth. Another means of holding the buds dormant in winter is to keep all twigs and buds covered with whitewash. This keeps down the temperature of the buds during warm days by reflecting heat that would be absorbed by the dark colored pigments in the twigs. The effect of color on the temperature of the twigs has been worked out by Whitten[1] who found as great as eight degrees centigrade difference between air temperature and that of purple twigs in winter. He also found by carefully sectioning buds that when the twigs are kept whitewashed during the winter they do not push as rapidly during warm periods as do buds on twigs not whitewashed, and in some springs, though not in all springs, he was able to cause the blooming time to come somewhat later. However, it would not be expected that such a process would affect the blooming time as much as it affects the amount of starting during warm days in early winter, since at blooming time the buds are for a good share of the time exposed to an optimum temperature for growth or nearly so, and during warm days in winter the air temperature is below the optimum temperature for growth and often even below the minimum temperature. The temperature of these winter twigs may be raised by absorbing sunlight to at least above the minimum temperature for growth and in some cases to the optimum temperature. Thus those who have expected whitewashing to cause an appreciably later blooming in spring would naturally, in many cases, be disappointed. In sections, however, where much killing occurs in winter following the starting of buds by warm periods, it should be expected to give good results.

While prolonging the rest period by causing growth late in winter by the above method applies only to sections far enough south that there would be a considerable number of warm days before the rest period is entirely ended (sections like the southern half of Missouri and farther south), the benefits from whitewashing would be expected to be as great say in New York or Canada in March before the optimum temperature for growth is reached as in Missouri, unless the sunlight should be less direct and there should be less increase in twig temperature caused by the absorption of light by the dark color. However, the cost of whitewashing an acre of trees,

[1]Mo. Agr. Exp. Sta. Bul 38, 1897. (Bibl. No. 114.) Das Verhältnis der Farbe, etc., 1902 (Bibl. No. 116).

(even assuming that the cost of one of the sprayings could be deducted since it could possibly be made to control either San Jose scale or peach leaf curl), would be in the neighborhood of $10 or $15 an acre, so before one would be justified in recommending such a method, it should be tried under orchard conditions for a long enough term of years to be sure that, say in twelve or fifteen years, enough peaches would be saved to justify the expense. There would unquestionably be some years when no benefit would be received in return for the whitewashing.

Killing Temperature of Peach Blossoms. A considerable amount of effort has been made to determine, under average conditions, the temperature at which the blossoms of peaches are killed. Unquestionably there is a considerable difference in the killing temperature of bloom in different years. The killing temperatures indicated by laboratory experiments will be given in the last part of this paper (Table 51.) Here the temperature at which bloom and young fruit has been killed in the orchard, and the condition which favor the smallest amount of killing will be discussed. During the spring of 1908 a freeze came on April 3rd when the temperature went to 24° F. at Columbia. Phenological notes taken that spring show that the first bloom on peach trees ranged from March 25th to March 30th, and full bloom ranged from April 5th to April 8th. The following table gives the percentage of bloom killed by this freeze:

TABLE 46. SHOWING THE PERCENTAGE OF PEACH BLOOM KILLED ON THE BASAL END AND THE OUTER END OF TWIGS BY THE FREEZE OF APRIL 3, 1908, WHEN THE TEMPERATURE WENT TO 24° F.

Variety	Basal half of twigs		End half of twigs	
	Number Buds	Percentage Killed	Number Buds	Percentage Killed
Oldmixon	159	70.44	363	84.39
Oldmixon	426	11.03	598	41.97
Oldmixon	648	15.12	828	67.23
Elberta	374	19.78	603	44.92
Elberta	121	38.	205	69.2
Elberta	163	52.1	143	71.3
Crawford's Early	95	5.26	155	25.16
Ortiz	623	46.70	553	55.50
Sneed	503	14.25	492	65.44
Sneed	354	45.48	413	53.75
Sneed	251	23.1	186	50.5
Kalamazoo	579	32.29	529	54.23
Family Favorite	483	26.70	431	63.80
Family Favorite	256	22.22	192	66.14
Golden Gate	129	85.2	72	50.
Dewey Cling	106	14.1	109	73.4
Dewey Cling	171	12.2	111	17.1
Elberta Seedling	151	5.9	216	73.
Elberta Seedling	1850	11.	980	16.3
Connet	395	11.1	507	43.1
Total No. buds	8367	....	8257	
Average percentage killed	....	27.24	....	53.68

Of course many of these blooms were not yet fully open and a much larger percentage of the flowers were fully open on the outer half of the twigs than on the basal half, as the following table will show:

TABLE 47. SHOWING PERCENTAGE OF BLOOM FULLY OPEN ON THE BASAL HALF AND THE OUTER HALF OF TWIGS BY APRIL 4, 1908

Variety	Basal Half		Outer half	
	Number Buds	Percentage Unopened	Number Buds	Percentage Unopened
Elberta Seedling	151	13.2	216	0.0
Elberta Seedling	1850	22.7	980	60.2
Connet	395	65.8	507	0.0
Sneed	174	16.0	252	0.4
Elberta	251	6.7	186	0.0

Not nearly so large a percentage of unopened as open bloom was killed, as the following table will show:

TABLE 48. SHOWING PERCENTAGE OF OPEN AND UNOPENED BLOOM KILLED BY THE FREEZE OF APRIL 4, 1908

Variety	Buds Open		Buds Unopened	
	Number Buds	Percentage Killed	Number Buds	Percentage Killed
Oldmixon Free	253	69.9	30	36.6
Oldmixon Free	326	25.4	241	15.3
Elberta	347	24.4	85	7.1
Elberta	309	51.13	26	1.1

It will be seen that enough fully open bloom was uninjured at this temperature, 24° F., for a good crop if the tree had a heavy set of bloom. In fact a minimum thermometer that checked with those of the U. S. Weather Bureau registered a temperature in the Missouri Experiment Station orchard of 23° F., so in some years at least, peach bloom may be expected to withstand a temperature that low.

Those three tables bringing out the facts, that the bloom just before the petals open will withstand lower temperatures than fully open flowers; that the flowers open more rapidly toward the tips of the twigs, and that therefore flowers on the outer half of the twigs are less likely to survive a spring frost coming before the bloom is fully open, suggest that the tree should be pruned to a sufficiently open head that the leaves at the base of the twigs will not be shaded off before fruit buds are formed.

The greater hardiness of unopened buds is apparently not due to the protection of the petals. In freezing 59 unopened blooms to a temperature of -3° C., 11.8 per cent of the pistils were killed while of 50 unopened bloom with the petals and stamens removed, no pistils were killed.

On April 30, 1908, the temperature fell to 28° F. in Columbia. The calyx tube was just breaking from the young fruit. The following table gives the percentage of fruits killed at Columbia:

TABLE 49. SHOWING PERCENTAGE OF YOUNG FRUITS FROM WHICH THE CALYX TUBE HAS JUST FALLEN KILLED BY A TEMPERATURE OF 28° F. APRIL 30, 1908

Variety	Number Fruits	Percentage Killed
Kalamazoo	749	26.3
Globe	279	22.5
Elberta	248	7.6
Elberta	301	.33
Elberta	300	5.6
Sneed	442	85.0
Alexander	411	76.8
Bonanza	454	5.94

It will be seen that large percentages of the fruits were killed only on early varieties like Sneed and Alexander that had reached a larger size. In the southern portion of Missouri where the fruit was larger, more was killed than at Columbia, though the temperature was higher, Koshkonong reporting 32° F. Of course in the lower land where most was killed, the temperature was naturally lower. It is apparently certain then that under average seasonal conditions, the older the fruit at the time of the freeze, the more easily it kills. It is possible that this would not be true in years when the bloom is pushed out very rapidly by exceptionally warm weather and when continuous cool weather follows the setting of the fruit. There is a rather general opinion that just when the calyx tube falls, the fruit is left more susceptible to cold because it has lost the insulation furnished by the calyx tube and requires time for adjustment. The fact that pistils of unopened flowers are not more easily killed when the external flower parts are removed, and the fact that buds of the peach were not more easily killed by freezing when the scales were entirely removed, would indicate that with the slow falling of the temperature that prevails under natural conditions, the insulation amounts to but little. It seems certainly true, from the experience of the season of 1908, that peach fruits are more tender a week or more after the calyx falls than say one day after it falls.

In examining, the fruits that were killed in the southern portion of the State in that year, in very many cases no injury was found to the flesh of the fruit, but the seeds were killed. Where the rate of fall of temperature is not too rapid under laboratory conditions, it is generally the seeds that are killed at the highest temperature. In fact from a large number of observations upon the results of

freezing peaches in the laboratory, the tissue kills in the following order, beginning with the most tender: the veins surrounding the seed, the kernel, the flesh. When the peach has reached considerable size, the woody covering surrounding the kernel is most hardy.

The greater tenderness of the seed may be accounted for by the difference in sap density. Thus the freezing point depression for the seed kernels, when they are large enough to separate from the seed practically, was found to be 0.765° C., while that for the same fruit with the kernels excluded was 1.075°.

At Koshkonong and at Goodman in 1908, following the freeze of April 30th, the fruit was injured least on the young vigorously growing trees. Thus at Koshkonong in the orchard of Mr. W. C. Paynter, weak trees in various parts of the orchard and trees on rocky, uncultivated portions had all the fruit killed, while vigorous trees further down the hill where the temperature must have been lower, as well as further up the hill, bore a full crop. In the case of killing of buds in winter, whether they have been started into growth or not, and in the case of killing of blossoms in spring in the southern part of Missouri, in some years the Elberta is one of the most tender varieties. Yet where it is the young fruit that is killed, the Elberta seems to be one of the most hardy varieties, at least other varieties were killed to a larger extent than Elberta in that year. Early varieties where the fruit was large at the time of the freeze uniformly killed worse than later ones. In Missouri, at least, early varieties do not bloom earlier than late varieties like Salway. In fact in extreme South Missouri such early Chinese Cling varieties as Sneed, Victor and Carman, on account of their longer rest period actually bloom later than late varieties like Elberta or Crawford's Late or Heath Cling, yet from the time of pollination there is much more rapid growth of the young fruit of the early varieties. Thus when the calyx tube is dropping from the Elberta peaches, the young Sneed will be much larger.

As to means of handling the trees to avoid injury at blooming time or after fruit is set, there is not so much that can be done except that, as mentioned above, in the most southern portions of the peach belt it is possible, by increasing the vigor of the tree, to cause the blooming to be later and, therefore, the young fruit at any given time after the bloom falls, to be smaller when the frost might come. This, of course, would not apply further North. Vigorous, trees may also have their fruit killed to a smaller extent because, in their tendency to make wood growth, the fruit develops apparently more slowly, at least fruit is practically always later in ripening on vig-

orous trees than on weakly growing trees. The whitewashing might also in some years have some effect on the amount of killing at blooming time, though it would probably have very slight effect on the amount of killing of young fruit after the bloom has fallen.

BREEDING VARIETIES HARDY UNDER SOUTH MISSOURI CONDITIONS

The most important ultimate means of reducing the amount of injury to both fruit buds and blossoms from low temperatures is by plant breeding. From what has been said above, for this southern region the varieties that would seem the most promising to use in breeding for hardiness would be some of the Chinese Cling group. With but few exceptions, the varieties of this group are more hardy than the average peaches, not only for this southern peach belt, but fortunately for the northern section also. Elberta, however, is a marked exception. It may be said further that the Chinese Cling comes nearly enough true to seed that it has been very useful in securing new varieties with size and shippping qualities desired. The quality, however, is rather low and the color poor so it must be crossed with something that will give color,—preferably yellow,—and quality. It seems highly probable that desirable hardy varieties of long rest period could be secured by crossing this strain with some high quality yellow fleshed peach like Fitzgerald, etc. However, the Elberta, the most promising example of this crossing, has certainly been a failure so far as hardiness is concerned. The Gold Drop and Lemon Free, being peaches of yellow flesh, fair quality and very hardy in bud for northern or southern climates, and rather hardy in wood, is promising, though so far we have been unable in the first cross to secure yellow flesh. The Hills Chili group may be among the hardiest varieties in both wood and bud for southern as well as for northern climates, but the quality is poor and resistance to rot so slight that it is a question whether they will be desirable for use in developing new hardy varieties for market conditions. Reference to Table 41 will show that the Green Twig varieties have as long rest periods as those of the Chinese Cling group. In addition to this they are hardy because their pale color reflects the sunlight instead of absorbing it;[1] yet their small size and indifferent quality, together with the fact that in all crosses with Purple Twig varieties they have taken the typical purple color, would seem

[1]J. C. Whitten, Mo. Agr. Exp. Sta. Bul. 38, 1897. (Bibl. No. 114). J. C. Whitten, Das Verhältnis der Farbe, etc., 1902. (Bibl. No. 117).

to eliminate them as promising material for breeding hardy varieties of desirable quality.

Hardiness of Seedlings. With reference to the opinion some people have that seedlings are, for some unaccountable reason, more hardy than budded fruits, it may be said that in the season of 1911 the Missouri Experiment Station was able to secure the percentage of buds killed by two different freezes, one before any buds had swelled and one after some swelling, from seedlings of a number of common varieties, the most important being seedlings of Chinese Cling, General Lee, Elberta and Family Favorite of the Chinese Cling group, Lewis, Early Michigan and Hills Chili of the Hills Chili group; and of the Snow, one of the hardy Green Twig varieties. The following table gives the results:

TABLE 50. SHOWING THE RELATIVE HARDINESS OF SEEDLINGS OF VARIOUS VARIETIES OF PEACH AS INDICATED BY PERCENTAGE OF BUDS KILLED BY A TEMPERATURE OF -8° F. JANUARY 5, 1911, AND BY A TEMPERATURE OF +6° F. FEB. 23, 1911.

Variety	Number of Buds	Percentage of Buds Killed Jan. 5, 1911	Percentage of Buds Killed Feb. 23, 1911	Percentage of Buds Alive After Both Freezes
Elberta	32	96.8	0.0	3.2
Elberta	89	79.8	7.8	12.4
Elberta	57	93.	5.4	1.6
Elberta	100	96.	4.	0.0
Elberta	133	66.9	9.	24.1
Elberta	36	100.	0.0	0.0
Elberta	107	80.4	12.2	7.4
Elberta	72	41.7	51.4	6.9
Elberta	103	77.6	16.6	5.8
Elberta	110	79.1	17.3	3.6
Elberta	60	85.	13.5	1.5
Elberta	28	96.4	0.0	3.6
Elberta	44	88.7	2.3	10.0
Elberta	60	66.3	20.0	13.7
Elberta	100	84.0	10.0	6.0
Elberta	38	78.9	2.6	18.5
Elberta	52	71.1	9.6	19.3
Elberta	54	98.2	1.8	0.0
Elberta	94	61.7	8.5	29.8
Elberta	9	100.0	0.0	0.0
Elberta	55	81.8	10.9	73.0
Elberta	26	88.4	11.6	0.0
Thurber	66	75.7	18.2	5.1
Thurber	63	46.0	33.4	20.6
Thurber	52	94.2	5.8	0.0
Thurber	90	75.5	18.1	6.4
Thurber	75	73.3	8.0	18.7
Thurber	136	69.8	13.3	16.9
Thurber	58	60.3	37.9	1.8
Thurber	80	41.2	20.0	38.8
Thurber	112	63.4	25.0	11.6
Thurber	101	75.2	9.9	14.9
Thurber	110	57.3	10.0	42.7
Thurber	32	71.9	6.2	21.9
Thurber	128	71.1	6.2	3.9
Thurber	56	57.1	42.1	10.8
Thurber	83	49.3	33.8	16.9
Thurber	122	31.9	51.7	16.4
Thurber	86	70.9	20.9	8.2
Thurber	160	28.1	28.8	43.1
Thurber	174	65.5	18.4	16.1
Thurber	143	68.5	25.2	6.3
Thurber	108	68.5	28.7	2.8
Thurber	63	82.5	12.7	4.8
Thurber	130	73.1	20.8	6.1
Thurber	150	67.3	22.0	10.7
Thurber	106	78.3	17.9	3.8

Variety	Number of Buds	Percentage of Buds Killed Jan. 5, 1911	Percentage of Buds Killed Feb. 23, 1911	Percentage of Buds Alive After Both Freezes
Thurber.............	48	77.1	18.8	4.1
Thurber.............	118	84.7	13.6	1.7
Thurber.............	120	56.6	28.4	15.0
Thurber.............	78	97.4	2.6	0.0
Thurber.............	188	75.0	22.3	2.7
Thurber.............	133	92.5	6.0	1.5
Thurber.............	134	70.9	15.6	3.5
Thurber.............	152	82.9	15.1	2.0
Family Favorite......	116	82.7	16.4	0.9
Family Favorite......	106	75.4	14.2	10.4
Family Favorite......	72	86.2	6.9	10.5
Family Favorite......	86	74.4	15.1	10.5
Family Favorite......	75	86.6	10.7	2.7
Family Favorite......	108	59.3	32.4	8.3
Family Favorite......	97	40.2	36.0	23.8
Family Favorite......	107	74.8	15.9	9.3
Family Favorite......	103	95.2	3.9	0.9
Family Favorite......	100	94.0	3.0	3.0
Family Favorite......	44	86.3	3.7	10.0
Family Favorite......	185	48.1	44.3	7.6
Family Favorite......	124	77.4	20.2	2.4
Family Favorite......	98	79.5	19.4	1.1
Family Favorite......	134	66.4	27.6	6.0
Family Favorite......	122	72.9	24.6	2.5
Family Favorite......	91	84.6	12.1	3.3
Family Favorite......	132	72.7	25.8	1.5
Family Favorite......	142	64.8	34.4	0.8
Family Favorite......	145	79.3	20.0	0.7
Family Favorite......	161	45.3	38.5	17.0
Family Favorite......	133	73.7	24.8	1.5
Family Favorite......	101	92.2	5.9	1.9
Family Favorite......	154	70.1	28.5	1.4
Family Favorite......	107	79.4	18.7	1.9
Family Favorite......	124	86.3	12.9	0.8
Snow...............	281	33.8	51.6	14.6
Snow...............	170	32.4	61.7	5.9
Snow...............	290	34.5	58.6	6.9
Snow...............	145	40.7	43.4	15.9
Snow...............	265	35.6	57.8	6.6
Snow...............	231	33.7	57.8	8.5
Snow...............	224	40.0	58.0	2.0
Snow...............	232	43.5	54.3	2.2
Snow...............	298	25.1	61.4	13.5
Snow...............	226	28.7	60.0	11.3
Hills Chili...........	161	74.5	24.9	0.6
Hills Chili...........	118	83.0	16.1	0.8
Hills Chili...........	77	79.2	19.5	1.3
Hills Chili...........	133	77.4	19.6	3.0
Hills Chili...........	153	67.3	32.0	0.7
Hills Chili...........	105	50.4	44.7	14.9
Hills Chili...........	136	61.8	30.8	7.4
Hills Chili...........	136	55.1	40.4	4.5
Hills Chili...........	111	54.0	34.3	11.7
Hills Chili...........	135	57.0	31.1	11.9

Variety	Number Buds	Percentage of Killed Jan. 5, 1911	Percentage of Killed Feb. 23, 1911	Percentage of Buds Alive After Both Freezes
Hills Chili...........	155	53.5	42.0	4.5
Hills Chili...........	154	55.2	36.3	8.5
Hills Chili...........	89	77.5	20.2	3.5
Hills Chili...........	233	49.8	45.5	4.7
Hills Chili...........	127	51.1	44.2	4.7
Early Michigan......	153	91.0	9.0	0.0
Early Michigan......	181	47.0	26.5	26.5
Early Michigan......	94	57.4	16.0	26.6
Early Michigan......	93	48.3	42.0	9.7
Early Michigan......	81	39.5	12.3	48.2
Early Michigan......	86	55.8	32.5	11.7
Early Michigan......	112	62.5	12.5	25.0
Early Michigan......	67	43.2	38.8	18.0
Early Michigan......	184	27.2	47.3	25.5
Early Michigan......	71	40.8	23.9	35.3
Early Michigan......	57	33.3	54.4	12.3
Early Michigan......	81	61.6	29.6	7.8
Early Michigan......	74	37.8	35.1	27.1
Early Michigan......	78	42.3	47.4	10.3
Early Michigan......	75	90.6	8.0	8.6
Early Michigan......	118	31.3	18.7	50.0
Early Michigan......	63	50.8	39.7	9.5
Early Michigan......	92	38.0	38.0	22.0
Early Michigan......	94	57.0	38.3	4.7
Lewis...............	75	82.7	13.3	4.0
Lewis...............	111	65.8	30.6	3.6
Lewis...............	115	40.9	31.3	27.8
Lewis...............	181	43.0	45.3	11.7
Lewis...............	152	51.9	38.2	9.9
Lewis...............	132	73.5	19.7	6.8
Lewis...............	124	62.1	29.0	8.9
General Lee.........	231	37.2	7.4	55.4
General Lee.........	130	50.0	16.1	30.0
General Lee.........	229	65.9	22.2	11.9
General Lee.........	153	73.2	22.2	4.6
General Lee.........	139	35.2	30.9	23.9
General Lee.........	100	47.0	30.0	23.0
General Lee.........	88	58.0	38.6	3.4
General Lee.........	109	86.2	9.2	4.0
General Lee.........	108	71.3	19.4	9.3
General Lee.........	108	38.9	40.7	20.4
General Lee.........	112	44.7	15.3	40.0
General Lee.........	170	22.4	40.0	37.6
General Lee.........	131	60.3	21.4	18.3
General Lee.........	115	63.4	15.7	20.9
General Lee.........	105	32.4	10.5	57.1
General Lee.........	101	39.6	17.8	42.6
General Lee.........	114	77.2	20.2	2.6
General Lee.........	109	75.3	12.8	11.9
General Lee.........	100	78.0	7.0	15.0
General Lee.........	102	50.0	28.5	21.5
General Lee.........	131	77.1	22.9	0.0
Chinese Cling........	154	63.6	35.0	1.4
Chinese Cling........	149	62.4	14.8	22.8

Variety	Number Buds	Percentage of Killed Jan. 5, 1911	Percentage of Killed Feb. 23, 1911	Percentage of Buds Alive After both Freezes
Chinese Cling........	118	37.2	28.1	34.7
Chinese Cling........	204	33.3	20.0	46.7
Chinese Cling........	64	84.4	12.5	3.1
Chinese Cling........	123	54.5	32.5	13.0
Chinese Cling........	121	39.6	38.1	21.3
Chinese Cling........	176	34.6	28.4	37.0
Chinese Cling........	219	34.2	13.2	51.6
Elberta, average........				10.92
Thurber, average........				11.5
Family Favorite, average........				5.4
Snow, average........				8.7
Hills Chili, average........				8.3
Early Michigan, average........				19.9
Lewis. average........				10.4
General Lee, average........				21.6
Chinese Cling, average........				23.5

It should be said that the varieties of the Hills Chili group are usually less vigorous growing trees, and since these seedlings were very closely planted, trees of the Hills Chili group would suffer more from shade in summer and thus have a larger percentage of buds not fully developed that are killed during even a mild winter. It will be seen that as a general thing those varieties which are most hardy have given seedlings that are also most hardy. By referring to this table and to Table 39 it will be seen also that these seedlings were generally not more hardy than the parents, though of course in the case of Elberta—a cross between the rather hardy Chinese Cling and Crawford's Early, and tender like Crawford's Early—some of the seedlings would tend to be more hardy than Elberta.

KILLING OF APPLES

Killing of the Roots. Killing of roots was not discussed for peaches because so far as can be learned, the killing of peach roots does not vary greatly from the killing of apple or of other fruit-tree roots. The killing of apple roots is probably a more common phenomenon than the killing of peach roots because peach roots are not so much more tender than apple roots as peach wood or peach fruit buds are more tender than apple wood or apple fruit buds. On account of the greater tenderness of wood and fruit buds, the peach tree

is not grown commercially in as severe climates as those in which apples are sometimes grown, yet killing of roots of peach trees is observed in fairly important commercial peach districts.[1]

Macoun[2] reports that killing of apple roots is fairly common in the northern portion of the apple growing section and says that the root killing they have had in Canada has been when apples were worked on seedlings of southern forms, and that since the crab has been used as stock, the killing has been much less.

Emerson[3] at the Nebraska Experiment Station planted apple trees in boxes two feet square and eighteen inches deep, each box having twenty-five young roots. The boxes were left out of doors about the middle of December, the soil having different percentages of moisture. The trees were examined on February 25. In an unprotected box containing 10.4 per cent of moisture, twenty roots were killed, only five remaining uninjured. Another unprotected box containing 15.2 per cent of moisture had nineteen killed and six injured. In a box containing 19.8 per cent of moisture, three were killed, ten injured and twelve uninjured. A box covered with straw mulch and containing 16 per cent of moisture had none of the roots killed, and only seven injured. A box covered occasionally with snow and containing 15.8 per cent of moisture had seven dead, eight injured and ten uninjured. No roots were injured in a box stored in a cool, dry cave, though it contained but 10 per cent of moisture. It is shown from this experiment that the low moisture content in itself did not do the harm, but the low moisture associated with low temperature. It does not seem, however, that one is justified in concluding, as Macoun apparently does, that plants at any given temperature kill worse in media with as small as 10 per cent of moisture than in media with 20 per cent of moisture. From experience here it would seem likely that the reverse is true. Careful temperature records would probably indicate that the temperature was lower in the boxes containing the smaller moisture content, and a dry soil will freeze more deeply than will a moist soil. Thus a mulch or sod or cover crop that tends to prevent evaporation from the soil will prevent its freezing so deeply and thus prevent injury to the roots by keeping the temperature higher.

Craig[4] studied root killing in Iowa for the winter of 1898-99. The injury was worst in light dry soils not protected by a cover crop

[1]Stone, Mass. (Hatch) Exp. Sta. Rpt. 1911, p. 66. (Bibl. No. 107). Green, W. J. and Ballou, F. H., Ohio Agr. Exp. Sta. Bul. 157, 1894. (Bibl. No. 48).
[2]Canada Exp. Farms, Rpt. 1907-8, pp. 110-16. (Bibl. No. 68).
[3]Nebraska Agr. Exp. Sta. Bul. 79, 1903. (Bibl. No. 33).
[4]Iowa Agr. Exp. Sta. Bul. 44, 1900. (Bibl. No. 25).

In case of light soils like the "loess" he found that deep planting helps to reduce the danger from root killing. Such soils would of course freeze more deeply and the temperature of the roots would be lower. He had little opportunity to observe directly the difference in hardiness of different stocks, except in one case where Shield Crab was used as stock, three-year nursery trees of Jonathan, Whitney, Grimes and Willow came through the winter in good condition, though nursery trees generally were badly injured. In examining injured trees he found that the stock at the union of stock and scion was often killed while immediately adjoining scion tissue was uninjured. He found scion roots to be more resistant than stock roots. This is in accordance with experience here in freezing roots in the laboratory. We have also found that the root system becomes more tender as it gets further from the crown. Emerson and others have observed that roots of trees are killed at a much higher temperature than are other tissues. This has been our experience. Results with freezing roots of orchard trees will be found in Tables 30, 31, 32, 33, and 34.

In case of one-year-old roots of the French crab used as stock by most of the nurserymen, about 5° C. to -8° C. is as low a temperature as they can be depended upon to withstand with no injury. Of 90 Jonathan apple grafts with French crab stock frozen to a temperature of -9° C. or lower and then planted in soil in the greenhouse, none lived. Four out of ten lived after being frozen to a temperature of -8° C.; three out of ten after a temperature of -7° C.; six out of ten after a temperature of -6° C., and practically all grew after a temperature of -5° C. These roots had not been exposed to a high temperature during the winter preceding the freezing, which was done from March 2, to March 18, 1911.

According to Craig and also Stone, when the roots are frozen, the results do not show to the inexperienced at once in spring. The trees will often bloom and usually the leaves will partially expand before the injury begins to show clearly. If only a part of the root system is killed, only certain connected branches will show the effects of the root killing.

Injury to Apple Wood. Macoun[1] lists a number of forms of winter injury to wood of fruit trees, especially the apple, as follows:

Bark splitting, which he says usually occurs when growth has continued late in autumn and an early summer has prevented the soil from freezing.

[1]Canada Exp. Farms Rpt. 1907-8, pp. 110-16. (Bibl. No. 68).

Trunk-splitting, sun scald, a killing of the bark on the south or southwest side of the tree which he reports very serious in northern and eastern Ontario and in the Province of Quebec.

Killing-back which he says results from inherent tenderness of the variety, or from insufficient maturity of the wood.

Crotch-injury, a killing of the cortex and perhaps other tissue in crotches of the limbs. Macoun, Morse, and Grossenbacher have studied this form of injury, and have found it to follow severe winters. Macoun and Morse attribute this injury to the lodging of ice in the crotch, while Grossenbacher attributes it to tearing caused by tensions developed by the shrinking of the tissue during its frozen condition. Grossenbacher observed this form of injury most commonly in the crotch formed by vigorously growing secondary branches.

Black-heart, a condition which follows the killing of the sap wood when the cambium is left alive to form new wood outside the killed area. It is troublesome to nurserymen in northern sections.

Trunk-injury or body injury, a killing of the older parts of the tree above the snow line. Macoun thinks this injury may be due to loss of water while the tree is frozen. Grossenbacher[1] describes a similar injury as Crown Rot, and attributes it to tearing from tension in the tree when frozen, and to a loss of water while frozen. He seemed to find it worse on the side of the tree trunk next to the prevailing winds.

The experience of the Missouri Experiment Station where the wood of the body of the tree, especially at the base of the tree trunk and at the crotches, becomes hardy more slowly in autumn in some years at least than does the tissue of the secondary branches or even the twigs (see Table 24) may have some bearing in connection with some of the above forms of injury, especially crotch injury and body injury, or crown rot. It seems possible that those forms of injury are merely direct freezing to death and that such injuries are more commonly found at the base of the trunk, or at the crotch, because on such years these are the most tender points.

Grossenbacher thawed the bark of a tree with warm water and worked the tree backward and forward when the temperature was -26° C. on January 8. In March practically all of the bark was found to be dead, showing apparently the characteristic browning of direct freezing to death. It would seem doubtful if this condition of complete death of the tissue with the browning would be found so soon

[1]New York (Geneva) Agr. Exp. Sta. Tech. Bul. 23, 1912. (Bibl. No. 50). New York (Geneva) Agr. Exp. Sta. Tech. Bul. 12, 1909. (Bibl. No. 51).

if it were merely a mechanical injury such as tearing loose of the bark. In this case it seems highly probable that the killing resulted from rapid temperature fall. The thawed tissue would fall to the temperature from which it was thawed, very rapidly, and from experience here with rapid freezing (see Table 20) it would seem probable that this tissue was killed by direct freezing the same as buds would be on account of this rapid lowering of the temperature.

Sun scald is generally thought to result from the effects of the heat gathered by the dark tissue that is in the direct sunlight. Since Macoun reports sun scald as being serious in climates as far north as the Province of Quebec, it would seem doubtful if there would be enough heat gathered on the sunny side of a tree trunk in winter there to raise the tissue to a temperature high enough for growth to take place. From experience here where the rate of temperature fall makes such a large difference in the killing, it seems highly probable that, at least in northern sections, sun scald may not result from the tissues starting into growth, but it more likely results from the temperature being raised to near the freezing point on sunny days during cold weather and dropping very rapidly to the temperature of the air as soon as the sun is off that part of the tree trunk.

As to varieties most hardy in wood under extreme conditions, Macoun[1] reports an examination of about 700 varieties in which he found that summer and fall apples were generally more hardy in wood than late winter varieties, probably because their wood reaches a condition of maturity earlier. In his experience some of the most hardy varieties were: Canada Baldwin, Winter Rose, Ontario, Stockton and McIntosh, all apples of northern origin. Oldenburg was cited by him as being one of the hardiest in wood.

The group of apples which Hedrick lists as hardy for the coldest part of the state of New York are: of summer apples, Yellow Transparent, Tetofsky, Oldenburg, Red Astrachan, and Lowland Raspberry; and of fall and winter apples, Wealthy, Hibernal, and Fameuse groups. Among the varieties that would not withstand the cold in the northern districts were: of summer apples, Early Harvest; and of fall and winter apples, Baldwin, Black Gilliflower, Jonathan, Rome, Winesap, and in the very coldest region, even the Northern Spy group.

The Killing of Apple Buds. The buds of apples will withstand much lower temperature than will the buds of peaches or of even plums and cherries, and Macoun reports the killing of buds of apples

[1]Canada Exp. Frt. Farms, Rpt. 1906, pp. 291-92. (Bibl. No. 70).

even in a very dormant condition. Whipple[1] describes a considerable amount of killing he has observed in Montana. When apple buds are killed it is not necessarily true that all parts of the buds are killed; generally only the flower parts, so that the buds will open in the spring into a whorl of leaves and for this reason the fact that any killing occurred may not be observed. He found also that in some cases not even all the flower parts were killed, but on opening, various malformations were to be observed; thus in some the pistils were entirely absent and in some both stamens and pistils. In some cases seedless apples were developed from such flowers.

Under Missouri conditions, especially in the Ozark region in the thinner soil, we have observed a considerable amount of killing by the freezes of December 9 and 29, 1909, when the temperature went to -5° F. and -8° F. respectively. During the same year buds of the York Imperial, as well as Jonathan, that had been largely killed by the same freeze, were sent in from points in Illinois. In most cases, however, the entire bud was killed. The Jonathan is the one variety in which a considerable amount of such injury has been observed. In low places where the cold air may settle and result in a very low temperature, all of the Jonathan buds were killed, even on healthy trees. However, in the Missouri Experiment Station orchard following a temperature of -20° F. on January 7, 1912 not a large percentage of the buds were killed. Of 200 Jonathan buds counted, 38 per cent were found to have been killed, and of the same number of Ben Davis buds counted, none were found dead. Of course some buds in which the flower parts were injured may have been overlooked. However, a good crop was secured in that year. In this orchard the trees had been kept in a healthy condition, while practically all the orchards observed, and all the orchards from which twigs were sent, were neglected orchards where the trees had made a weak growth the summer before and had set their fruit buds very early, probably pushing them too far early in the season before this freeze.

Killing of Apple Bloom. Killing of the flowers is a common form of injury to apples resulting from low temperatures, at least under Missouri conditions. An effort was made to determine what is approximately the killing temperature of the full bloom of apples. The following table gives the results of freezings with apple, peach and other fruits, just before the bloom opens, in full bloom, just after the bloom falls, and when the fruit is as large as it has been when it

[1]Montana Agr. Exp Sta. Bul. 91, 1912. (Bibl. No. 113).

was killed in Missouri. The material was generally kept at the minimum for thirty minutes. The temperature fall was as slow as it could be made with the freezer used.

TABLE 51. GIVING RESULTS OF ARTIFICIAL FREEZING OF FRUIT BLOSSOMS

Material	Condition of Flowers When Frozen	Date	Temperature	Number Blossoms	Percentage Killed
Apple, Ben Davis......	Not fully open	Apr. 14,'11	27.5	87	31.0
Peach, Elberta Seedling	Fully open....	Apr. 14,'11	27.5	66	6.1
Pear, Kieffer..........	Fully open.....	Apr. 14,'11	27.5	40	0.0
Plum, Wild Goose......	Fully open....	Apr. 14,'11	27.5	60	0.0
Cherry...............	Not fully open	Apr. 14,'11	27.5	97	50.5
Apple, Stannard.......	Fully open....	Apr. 15,'11	27.5	45	40.0
Peach, Elberta Seedling	Fully open....	Apr. 15,'11	27.5	87	60.9
Pear, Kieffer..........	Fully open....	Apr. 15,'11	27.5	70	32.8
Plum, Wild Goose......	Fully open....	Apr. 15,'11	27.5	50	0.0
Cherry...............	Fully open....	Apr. 15,'11	27.5	91	58.2
Apple, Ben Davis......	Fully open....	Apr. 15,'11	27.5	61	22.9
Peach, Rareripe........	Petals falling..	Apr. 28,'13	26.6	86	2.5
Apple, Jonathan........	Not fully open	Apr. 28,'13	26.6	100	8.0
Apple, Jonathan.......	Fully open....	Apr. 28,'13	26.6	78	56.4
Apple, Jonathan.......	Petals falling..	Apr. 28,'13	26.6	120	18.0
Cherry, English Morello	Fully open....	Apr. 28,'13	26.6	130	48.5
Cherry, English Morello	Petals falling..	Apr. 28,'13	26.6	107	67.1
Apple, Rome Beauty...	Fully open....	May 1,'13	24.8	83	40.9
Peach, Hiley..........	Young fruit...	May 1,'13	24.8	76	1.3
Cherry, Montmorency..	Fully open....	May 1,'13	24.8	40	52.5
Apple, Jonathan.......	Young fruit....	May 10,'13	26.6	53	71.7
Peach, Early Bernard..	Young fruit...	May 10,'13	26.6	74	94.6
Peach, Gold Drop......	Young fruit...	May 10,'13	26.6	65	75.4
Cherry, Dyehouse......	Young fruit...	May 10,'13	26.6	44	70.4
Plum, Wild Goose......	Young fruit...	May 10,'13	26.6	93	16.1
Pear, Kieffer..........	Young fruit...	May 10,'13	26.6	32	78.1
Apple, Jonathan.......	Young fruit...	May 17,'13	24.8	19	68.4
Peach, Lewis..........	Young fruit...	May 17,'13	24.8	23	43.5
Cherry, Dyehouse......	Young fruit...	May 17,'13	24.8	15	66.6

These artificial freezings are not accurate in determining the minimum temperature which the bloom, etc., will withstand, since it is not possible to duplicate in the freezer the rate of temperature fall, etc., outside, nor is it possible to make two freezings exactly duplicate each other. However, it is safe to conclude from this table that the unopened flowers are slightly more hardy than the fully open ones, and that the fruits are slightly more tender than the flowers. The difference with apples, judging from these freezings and from our observations on freezings outside, is not so great as with peaches.

These results indicate that peaches, either in blossom or young fruit, will withstand slightly lower temperatures than will apples. The greater hardiness of the peach bloom is probably under-emphasized in this table. In the year 1911 the Elberta Seedling peach tree came into full bloom on April 12, while the Ben Davis apple came into full bloom on April 18 to 22, and the Stannard apple on April 20. It is almost certain then that the peach blossoms listed as fully open were older than the apple blossoms so listed and had been pollinated and had started rapid growth, while the apples had not. In 1913 the Early Bernard peach came into full bloom on April 11, and the Hiley and Rareripe on April 16-17, while Jonathan apple came into full bloom April 24, and the Rome on April 29. Here then the young fruits of the peach were older than were the young apple fruits used. From results of freezes as seen in the orchard, we are convinced that at times, at least, bloom and young fruit of peaches will withstand lower temperatures than will apple bloom or young fruit.

The freeze of April 30, 1908, when the temperature in Columbia went to 28° F., killed only the percentages of young peach fruit shown in Table 49, and an excellent crop was secured from the peach trees the summer of 1908, while practically all the apple fruit was killed; yet the peach fruit had been set longer. The peach trees in that year came into full bloom from April 5 to 7, while varieties of apples like Ben Davis, Jonathan and Grimes, fruit of which was all killed in this orchard, came into bloom from April 15 to 17. The Ingram apple in that year came into full bloom on April 22 to 24 and had some bloom left when the freeze came. It had a fair crop of apples left, and the Ralls, which came into full bloom from April 23 to 25 and had a considerable amount of open bloom when the freeze came, had very few fruits or blooms killed. If peach blooms or fruits are more often killed in spring than that of the apple, it is because peaches usually bloom considerably earlier.

In avoiding a loss from low temperatures in spring, the most important factor is late blooming. Some varieties like Ingram and Ralls bloom so much later than ordinary varieties that, except in very few sections of the State, they are practically never killed by spring frosts. Other varieties that apparently are seldom killed under Missouri conditions are Benoni and Mother, according to information furnished by Mr. F. W. Faurot, formerly of the Missouri State Fruit Experiment Station at Mountain Grove, Missouri. Growers in southern Illinois also report Benoni as being rather safe from frosts. Rome Beauty on many years blooms enough later than other varieties to escape injury. Whether in the southern portion

of the apple growing region this blooming in spring can be caused to be delayed by prolonging the rest period, as in the case of peaches, has not been studied. Mr. Faurot however, tells of an instance in which cultivated trees were three days later in coming into bloom than uncultivated trees of the same variety, with like treatment in every other way. The fact that the buds on well kept Jonathan orchards on good soil were not killed to such a large extent by the freezes of December, 1909, as were the buds on trees in neglected orchards that had gone dormant much earlier the season before, seems to indicate that the buds in early winter, at least, are kept dormant later by keeping the tree vigorous.

An opinion is held by some fruit growers and horticulturists that if the tree is in a vigorous condition the bloom or young fruit will withstand lower temperatures because of the healthier condition of the bloom or young fruit. Three Gano apple trees on the Station grounds have been left unsprayed and uncultivated and are in a weak condition, one of them in a very weak condition. At times bloom or young fruit from these have been frozen along with bloom or young fruit from well kept Gano trees. These weak trees and the vigorous trees in Columbia bloomed at the same time. The following table gives the results:

TABLE 52. SHOWING RELATIVE HARDINESS OF BLOOM AND FRUIT FROM WEAK AND FROM VIGOROUS GANO APPLE TREES

Material	Date	Temperature	Number Frozen	Percentage Killed
Vigorous sprayed tree	May 1,'12	−3	28	71.4
Weak unsprayed tree	May 1,'12	−3	16	87.5
Vigorous sprayed tree	May 1,'12	−5	50	100.0
Weak unsprayed tree	May 1,'12	−5	40	95.0
Vigorous sprayed tree	May 4,'12	−2	52	21.1
Weak unsprayed tree	May 4,'12	−2	56	19.7
Very weak unsprayed tree	May 4,'12	−2	46	32.6
Vigorous sprayed tree (fruit ⅜ in. in dia.)	May 18,'12	−4	98	81.9
Very weak unsprayed tree (fruit ⅛ in. in dia.)	May 18,'12	−4	79	83.5

It will thus be seen that there is no constant difference in the hardiness of the fruit from the weak and the vigorous tree. Casual observers may mistake loss of crop from cool weather at blooming

time, poor pollination, or other reasons, for injury from freezing. It is certainly true that a poor set of fruit is often attributed to frosts when a careful observation following the frost would have shown that no bloom or fruits were killed.

KILLING OF CHERRIES AND PLUMS

Killing of various tissues of other fruits has not been extensively studied at this Station, except as described in the early part of this paper. As to killing of buds, Macoun[1] states that under Canadian conditions, especially in the Province of Quebec when away from the protection of a body of open water, European and Japanese plums, and cherries are injured more or less every winter. He lists Mount Royal and Raynes as new varieties very hardy in bud. Japanese plum fruit buds have killed in Missouri only after cold periods following sufficient warm weather to start them into growth.

In case of killing by spring freezes, the Wild Goose plum is very resistant to low temperature as will be seen by reference to Table 51. On April 24, 1910, when all other fruits, in the Station orchard, except Ingram and Ralls apples which were just in bloom, were killed by a temperature of 27° F. Wild Goose plums were uninjured though they had reached a diameter of 3-16 of an inch. We are not prepared to say, however, that the young fruit of the Wild Goose plum is not more hardy than the bloom.

In the case of cherries observations have been made on the killing of the Early Richmond cherry buds to a large extent, and other varieties to a small extent, especially by cold periods following warm weather. On January 7, 1912, the following percentages of fully dormant cherry buds were killed by a temperature of -20° F.: Early Richmond, of 200 buds counted, 52.5 per cent were killed; Montmorency, of 150 buds counted, 12 per cent were killed; Dyehouse, of 175 buds counted, 11.4 per cent were killed.

Macoun holds that fruit buds of cherry, peach and Japanese and European plum kill more easily than do the buds of the apple and the pear because they have less protection from evaporation. Goff[2] found a larger percentage of cherry buds to survive a temperature of -27½° F. in Wisconsin in February, 1899, in the central portion of the tree than on the ends of the outer branches. He concludes that this results because those near the center of the tree were partially protected from drying winds. It does not seem probable

[1]Canada Exp. Farms, Rpt. 1907-8, pp. 110-16. (Bibl. No. 68).
[2]16th An. Rpt. Wis. Agr. Exp. Sta. pp. 283-88, 1899. (Bibl. No. 46).

that evaporation affects the killing of buds unless it be indirectly by the drying out of the twigs. Cherry buds are more tender than apple buds when exposed to sudden freezes like that at Columbia, Missouri, January 7, 1912. They are also more tender when frozen in the laboratory under conditions such that buds with the scales removed kill no worse than normal buds. Evaporation could certainly play no part there. The buds at the ends of peach twigs are generally more tender than those near the base of the twigs or on spurs along the branches, but buds on the ends of twigs down in the tree are as tender as any. It is probable that the buds that Goff found more hardy toward the center of the tree were formed earlier in summer and were more mature when the freeze came.

One of the most promising means of avoiding loss from low temperatures is by orchard heating, burning oil, coal or other material. In some sections this practice is followed profitably, and it is recommended in others. This subject is being studied at the Missouri Experiment Station by Dr. W. L. Howard. In the work here reported, no data has been gathered that is of value in a study of orchard heating, unless the results with freezing bloom and young fruit may be of some value in determining the temperature at which heaters should be lighted. Data on the killing temperature of the bloom of fruit to be protected is very essential in orchard heating, otherwise the heaters will too often be lighted and large expense incurred when it is unnecessary, or perhaps sometimes they may not be lighted when it is necessary, and loss will be incurred. A study of orchard heating, like a study of the value of whitewashing as a means of preventing killing from cold, should be carried on through a large number of years since heating involves an expense certainly not less than an average of $10 or $12 per acre a year, besides a large initial investment, and the mere fact that the crop can be saved by heating is no positive indication that in a period of twelve or fifteen years enough crops will be saved, in spite of accidents inherent in the method of heating, to pay for the cost of heating.

ACKNOWLEDGEMENTS

This work was begun under the direction of Dr. J. C. Whitten of the Department of Horticulture of the Missouri Agricultural Experiment Station, and advice has been received from him throughout the work. Advice has also been received from Professor W. L. Howard of the Department of Horticulture, Professors B. M. Duggar, C. Stuart Gager, and G. M. Reed of the Department of Botany;

and Dr. Hermann Schlundt of the Department of Chemistry of the University of Missouri has been repeatedly called upon for information where the work in this bulletin required knowledge of physical chemistry. Mr. A. J. Heinicke and other advanced students, who have from time to time been connected with the Department, have assisted in the laboratory in securing the data here published. All chemical analyses have been made under the direction of Professor P. F. Trowbridge of the Department of Agricultural Chemistry.

Professor U. P. Hedrick of the Geneva, New York, Experiment Station and Professor H. P. Stuckey of the Georgia Agricultural Experiment Station, furnished twigs used in some of the freezings reported in this bulletin. Professor Hedrick and also Professor R. A. Emerson of Lincoln, Nebraska, were kind enough to furnish publications that were not available here, as well as repeatedly to give advice.

Grateful acknowledgment is made to these men and to others mentioned in this bulletin who have been kind enough to furnish information.

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